



Hand-Held Terahertz Imaging

David Zimdars

Manager of Terahertz Research and
Development

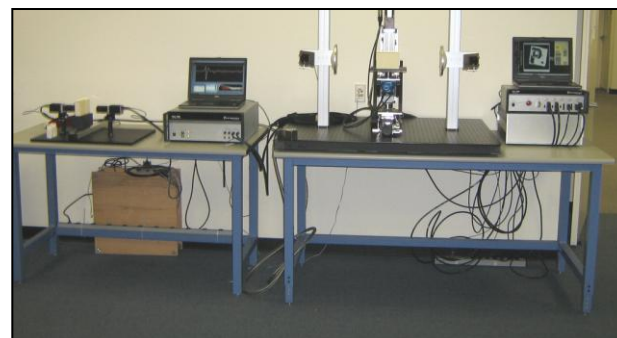
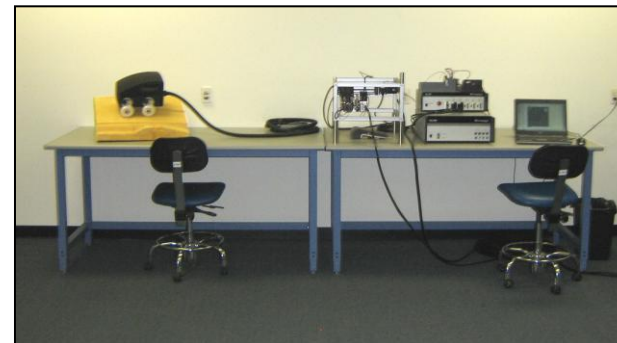
In-Space NDI Technology Workshop

Gillruth Center – NASA / JSC

Wednesday February 29, 2012

Picometrix, LLC

- Formed in 1992 in Ann Arbor, Michigan
- Subsidiary of Advanced Photonix, Inc. since 2005
 - NYSE: AMEX listed (API)
 - Leading supplier of TD-THz instrumentation and optical receivers utilizing Si, GaAs and InGaAs
 - Industrial, military, homeland security, medical and telecom markets
- Picometrix 50,000 sq. ft. with four TD-THz application labs



**2925 Boardwalk
Ann Arbor, MI 48104, USA
(734) 864-5600**

**sales@picometrix.com
www.picometrix.com
www.advancedphotonix.com**



T-Ray 4000[®] Modular Product Line

NDE and Imaging

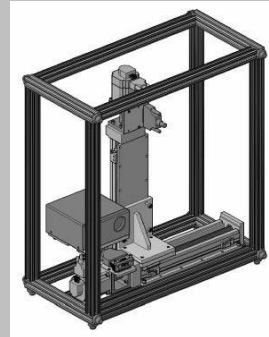
Imaging Station[™]



Motion Controller



Custom Gantry

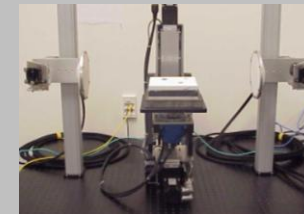


T-Scanner[™]



New for 2010!

T-Ray[®] Computed Tomography

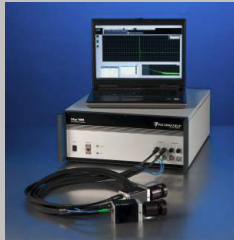


New for 2010!

NDE and Imaging

Lab and Custom Configured R&D

T-Ray 4000[®] Base System



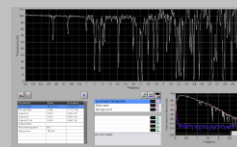
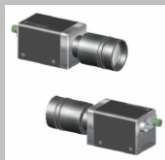
T-Ray 4000[®] Control Unit
100 Hz and 1KHz



Spectroscopy Station[™]



T-Ray[®] Transmitter and Receiver



T-Ray[®] Explorer[™] Software



T-Ray[®] T-Gauge[™]



New for 2010!

Industrial Online
Measurement

Evolution of T-Ray® Instrumentation Platform

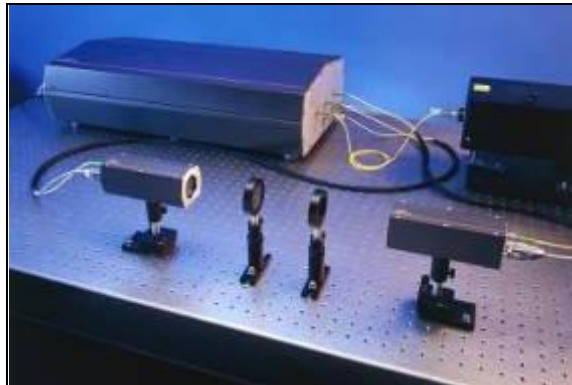
**1996 PhD-Built Discrete
Component Lab Setup
(Bell Labs)**



**2002 Picometrix TMIS™ and
2004 QA1000™
All-In-One Control Unit**



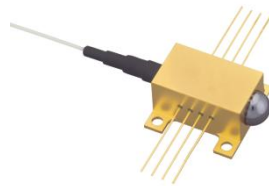
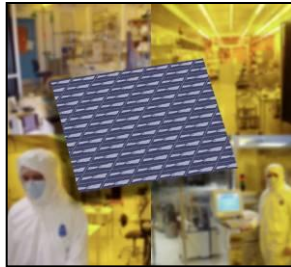
**2007 Picometrix T-Ray 4000®
Industrial 19 in. Rack Mount
Portable Control Unit**



**1999 Picometrix T-Ray® 2000
Patented Freely Positionable
Fiber Optic Driven THz Modules and Sensor
Technology**

Vertically Integrated

- Grow custom epitaxial structures for high speed photoconducting antennas
- Microfabricate T-Ray® antennas
- Assemble rugged fiber-coupled transmitters and receiver modules
- Engineer and manufacture control unit and high-speed optical subsystems
- Program control / analysis software



Common Control Unit: Flexibility & Expansion



NDE and Imaging

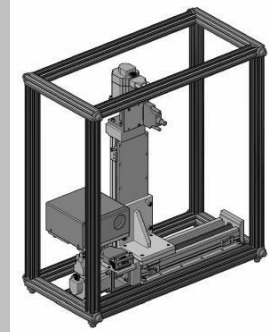
Imaging Station™



Motion Controller



Custom Gantry

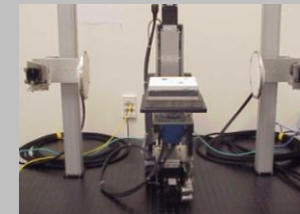


T-Scanner™



New for 2010!

T-Ray® Computed Tomography

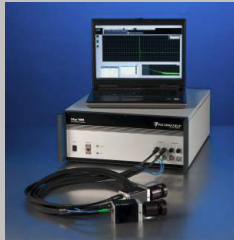


New for 2010!

NDE and Imaging

Lab and Custom Configured R&D

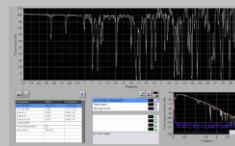
T-Ray 4000®
Base System



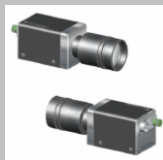
T-Ray 4000®
Control Unit
100 Hz and 1KHz



Spectroscopy
Station™



T-Ray® Transmitter
and Receiver



T-Ray®
Explorer™
Software



T-Ray® T-Gauge™



New for 2010!

Industrial Online
Measurement

T-Ray 4000[®] Control Unit

- Interchangeable plug-in sensors
- Multiple sensor heads available
- Transmission or reflection
- Two measurement channels
- Remote sensors up to 50 m
- High-speed waveform acquisition (A-Scan)
 - 100 Hz 320 ps
 - 1000 Hz 80 ps
- Stable measurement
- Dedicated software packages
 - THz waveform acquisition and analysis
 - Imaging
 - Spectroscopy
- Portable, 19 in. rack mountable
- Robust packaging
- 0 – 35 °C
- Low RF emission



Industrial Requirements

- Compact, reliable, robust
- Tolerant of the environment
 - Temperature, dust, explosive atmosphere (sensors)
- Non-interfering with the environment
 - Low RF emissions, certifications (UL, CE, FCC)
- High speed
 - Waveform acquisition, processing
 - Imaging and process control
- Easy to use
 - Familiar to industrial personnel

Software for Data Acq., Spectra & Imaging

NDE and Imaging

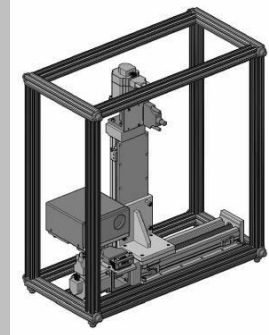
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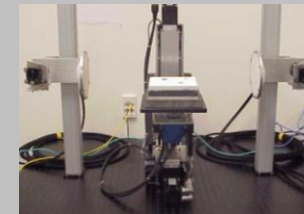


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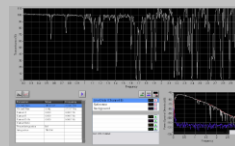
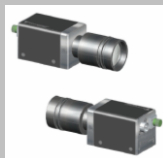
T-Ray 4000® Control Unit
100 Hz and 1KHz



Spectroscopy Station™



T-Ray® Transmitter and Receiver



T-Ray® Explorer™ Software



T-Ray® T-Gauge™

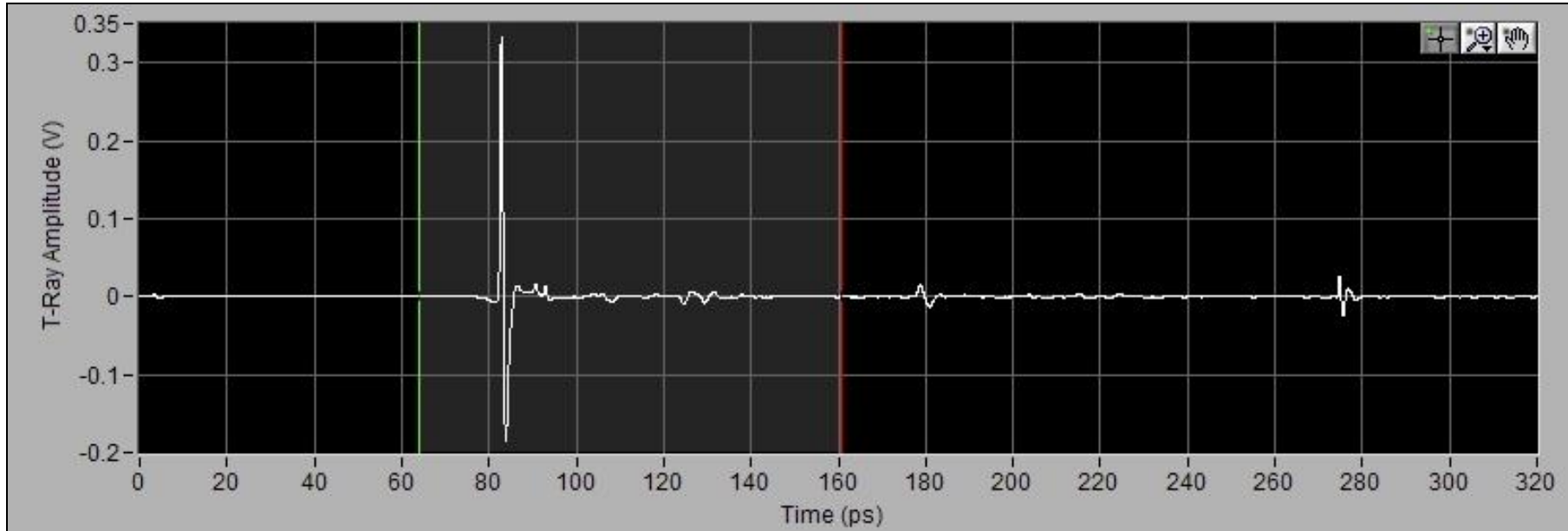


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NDE and Imaging

Industrial Online
Measurement

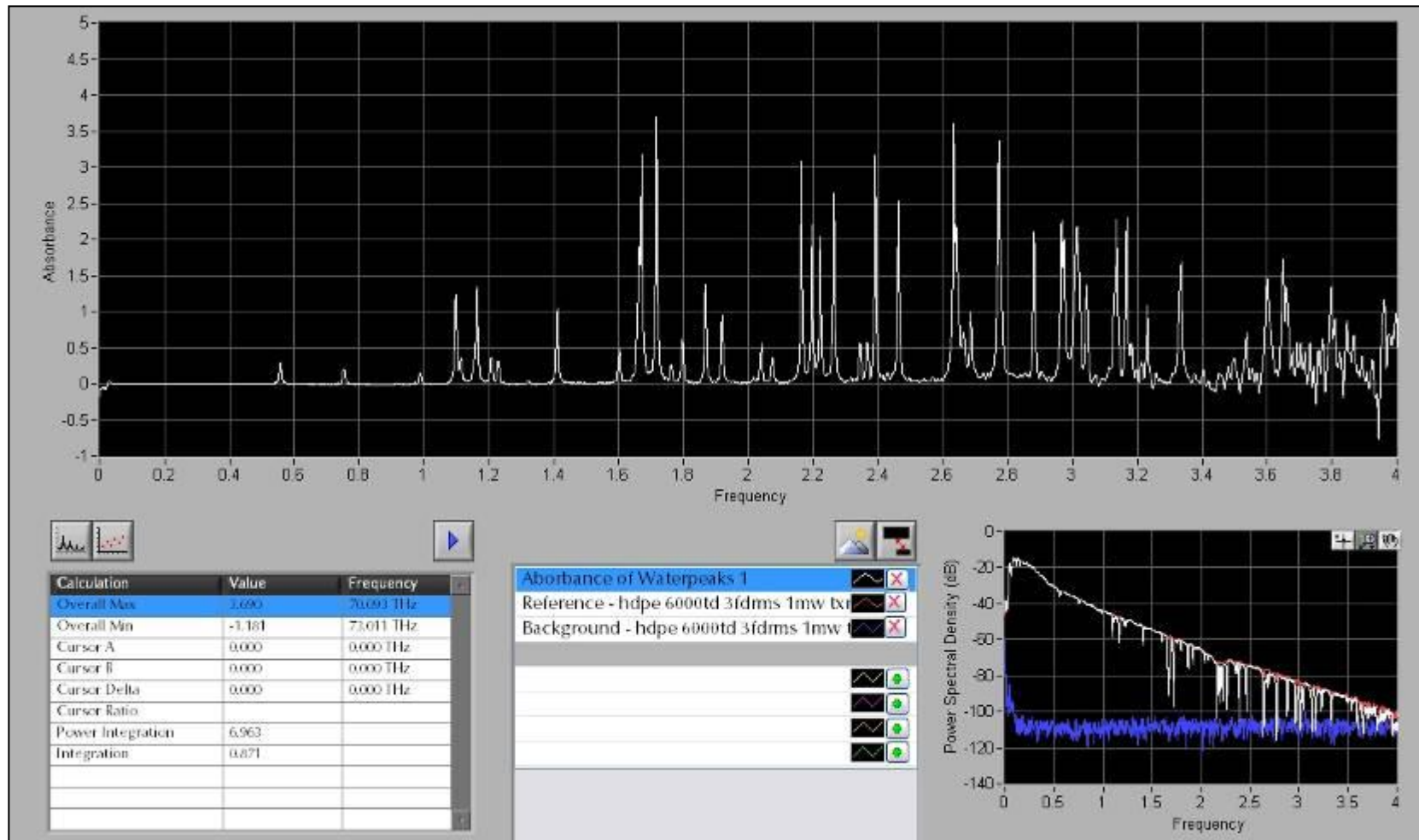
Terahertz pulse (TD-THz)



- Time Domain
 - Time of flight
 - Weighing
 - Thickness
 - Index
 - Scattering

Frequency 0.05 – 4 THz
Wavelengths 6 – 0.1 mm
cm⁻¹ 1.7 - 100

Water Vapor Spectrum



Rapid scan resolution: 2-3 GHz (less than the pressure broadening at STP)

Solutions for NDE and Imaging

NDE and Imaging

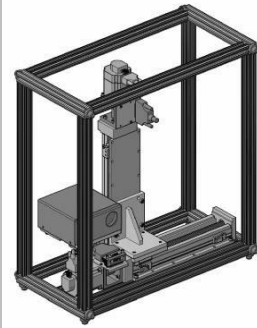
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Motion Controller



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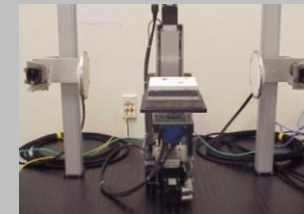


T-Scanner™



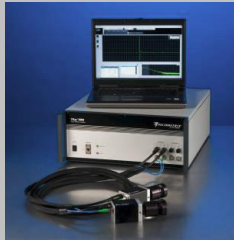
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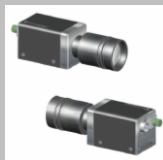
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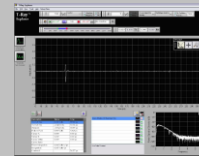
Spectroscopy
Station™



T-Ray® Transmitter
and Receiver



T-Ray®
Explorer™
Software



T-Ray® T-Gauge™



New for 2010!

NDE and Imaging

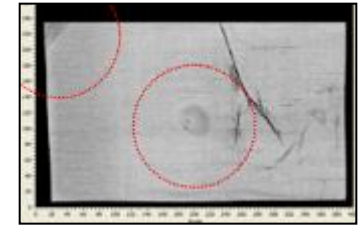
Industrial Online
Measurement

Aerospace applications

Picometrix T-Ray 4000®



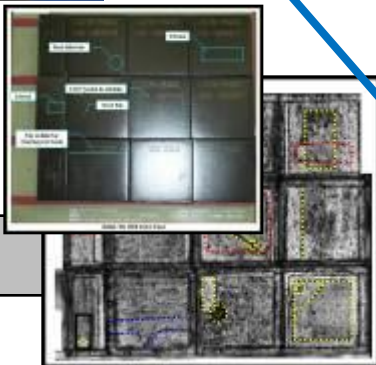
Radome delamination and water intrusion;
with Hill AFB



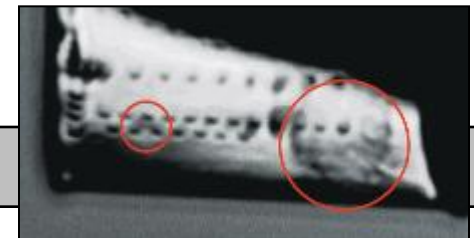
F35 Intake Specialty Coating thickness
measurement; with WPAFB and NGC Palmdale



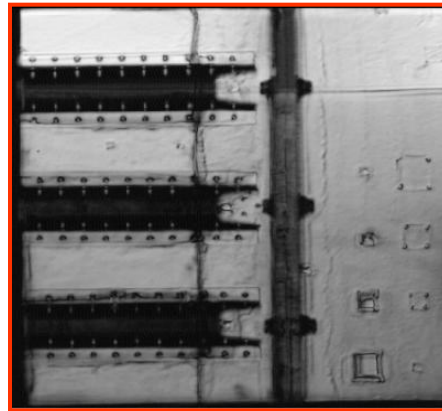
Space Shuttle: ET tank foam NDE;
Orbiter TPS Tiles-hidden corrosion detection;
Next Gen Orion and Ares Applications: NASA



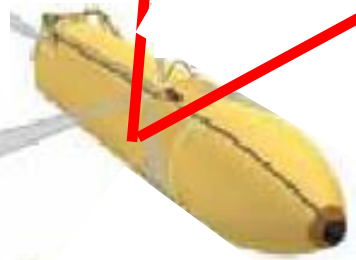
Aeroturbine Thermal Barrier Coating
measurement; with Navy STTR



Deployed Application Shuttle ET Tank SOFI



*Intertank / LH2 Tank Flange
Closeout Enhancement*



Reflection Imaging

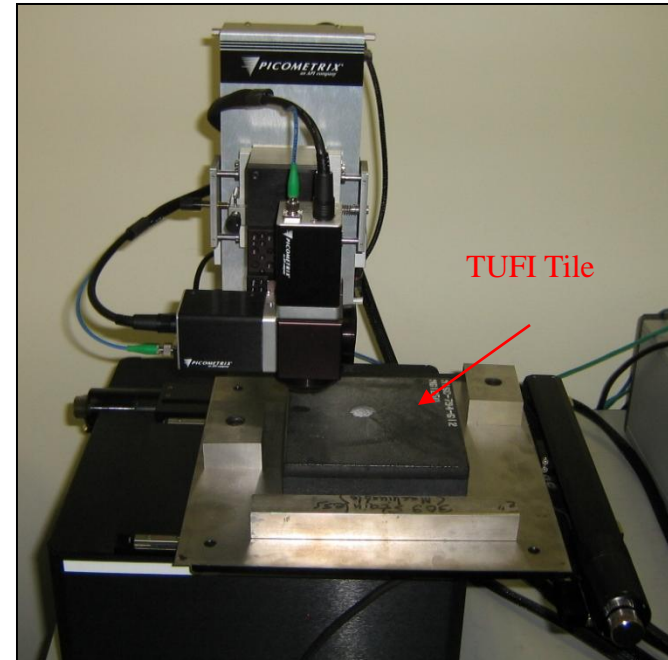
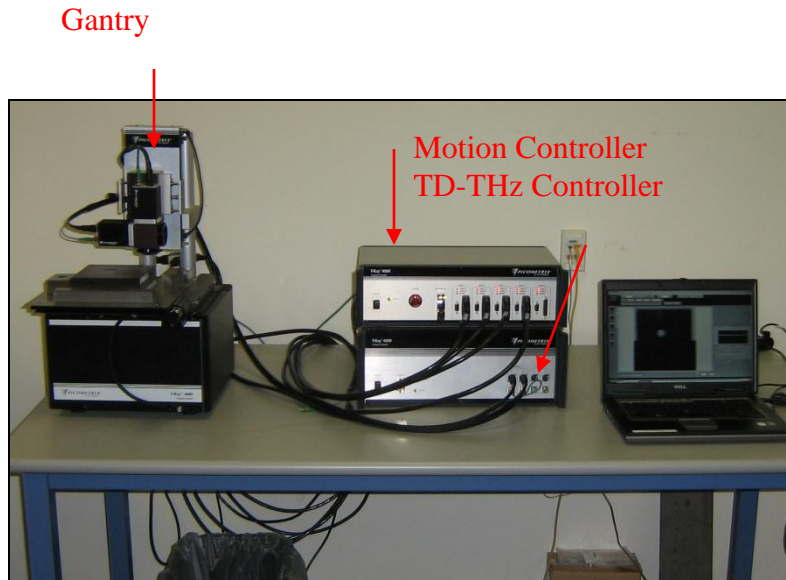
1.5 mm pixels 0.2 m/s

~ 1m x 1m

Youtube Video of NASA Scanning Tank with T-Ray 4000®

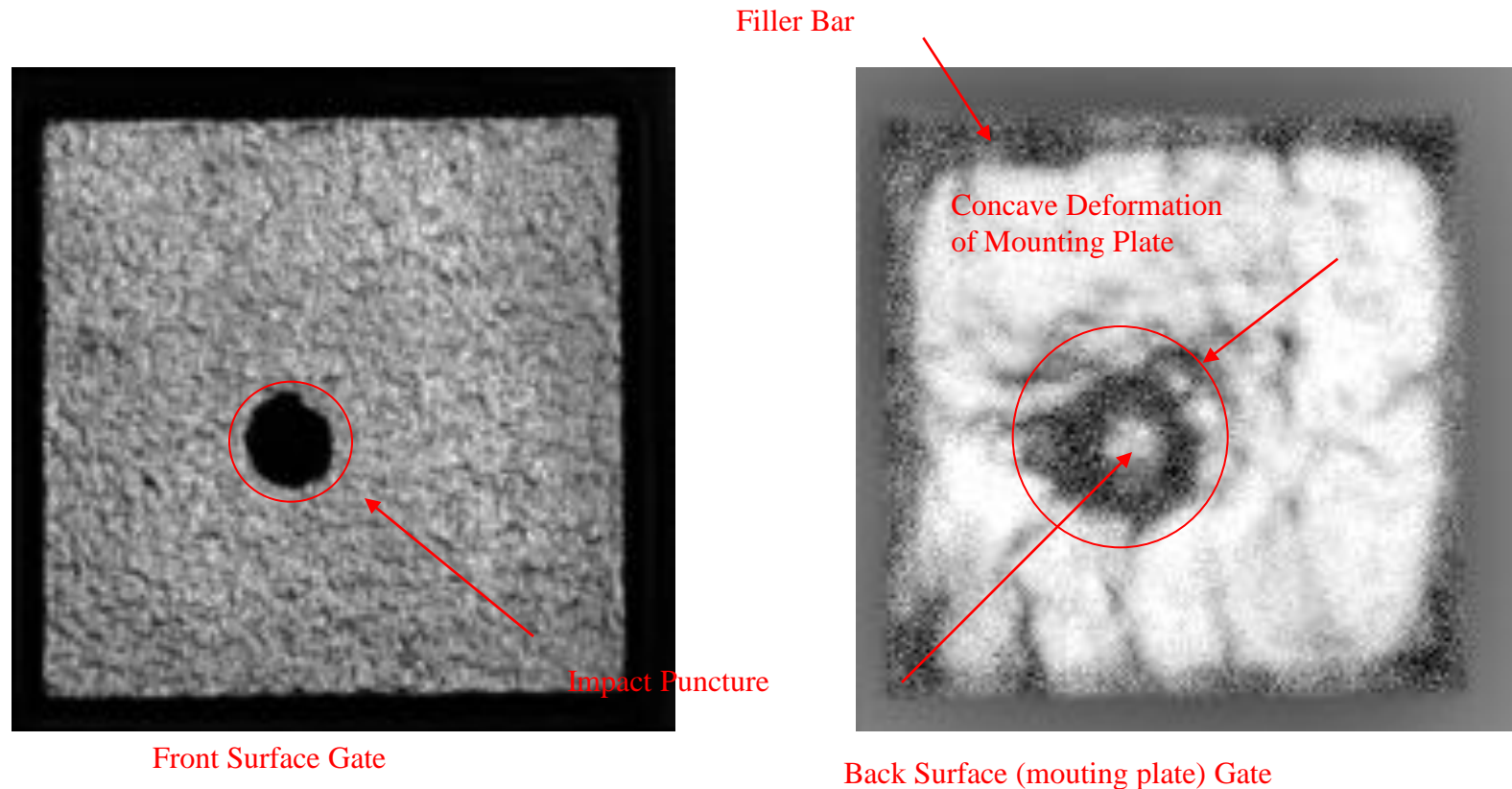
http://www.youtube.com/watch?v=nRrZU_c5zN8

TD-THz Reflection Imager



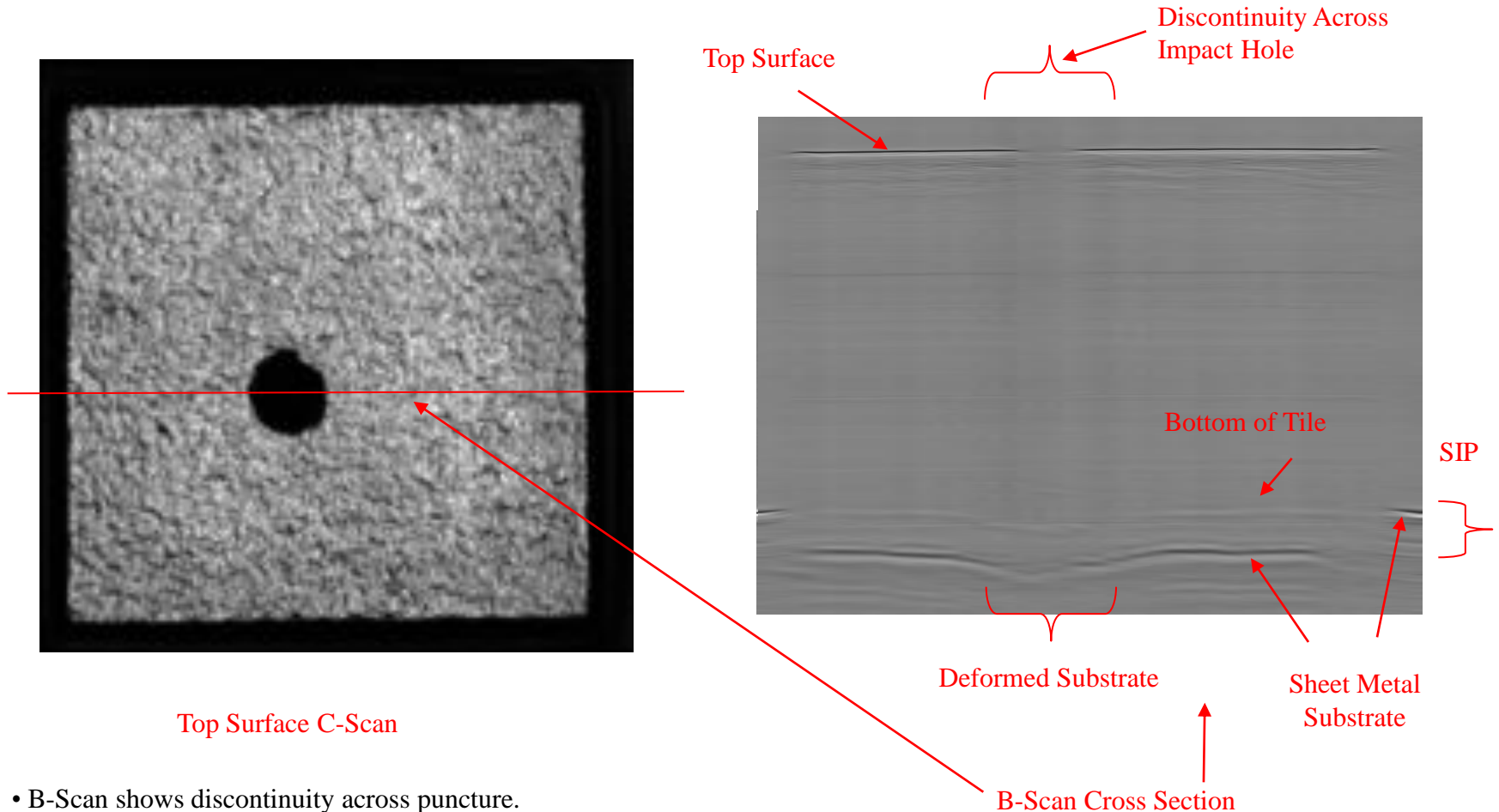
- T-Ray 4000 control unit, imaging station, motion controller, and laptop computer.
- Co-linear reflection adaptor with 3 in. f.l. 1.5 in. diam. lens, F/2. Snub bow-tie transmitter to bow-tie receiver.

TUFI Tile TD-THz C-Scans



- Tile dimensions L6 in. x W6 in. x H1.72
- Mounted on L12 in. x W12 in. 1/32 in. thick aluminum sheet
- Aluminum mounting sheet metal was deformed into a bulge and punctured/torn.
- Front: Power integration between 0.3 and 2 THz
- Back: Centroid delay with 0.3 to 0.8 THz bandpass filter.

TUFI Tile TD-THz B-Scan



- B-Scan shows discontinuity across puncture.
- Concave deformity of impact into substrate indicated.
- B-Scan shows material compacted from impact onto surface of the substrate on the bottom of the hole. Confirmed visually.

T-Ray® Computed Tomography

NDE and Imaging

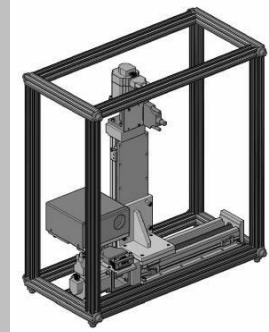
Imaging Station™



Motion Controller



Custom Gantry



T-Scanner™



New for 2010!

NDE and Imaging

Lab and Custom Configured R&D

**T-Ray 4000®
Base System**



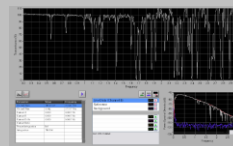
**T-Ray 4000®
Control Unit**
100 Hz and 1KHz



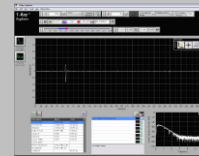
**Spectroscopy
Station™**



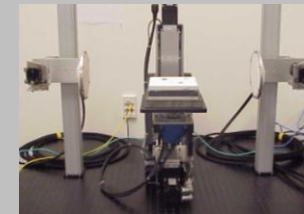
**T-Ray® Transmitter
and Receiver**



**T-Ray®
Explorer™
Software**



**T-Ray® Computed
Tomography**



New for 2010!

T-Ray® T-Gauge™

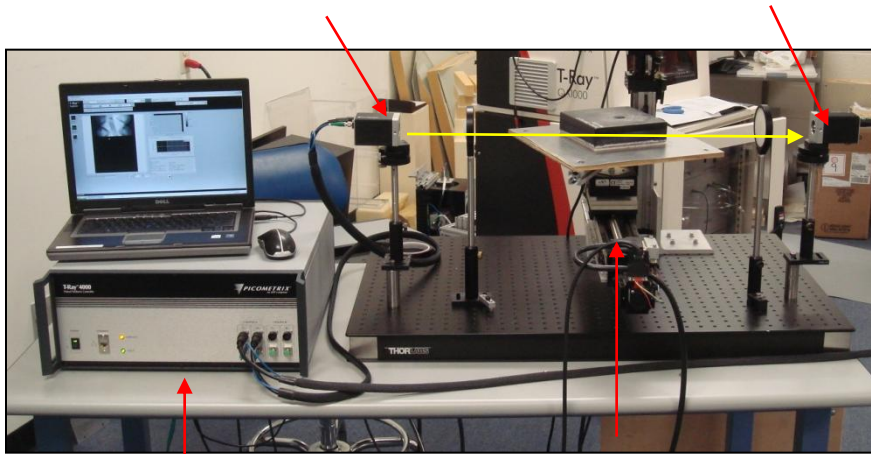


New for 2010!

Industrial Online
Measurement

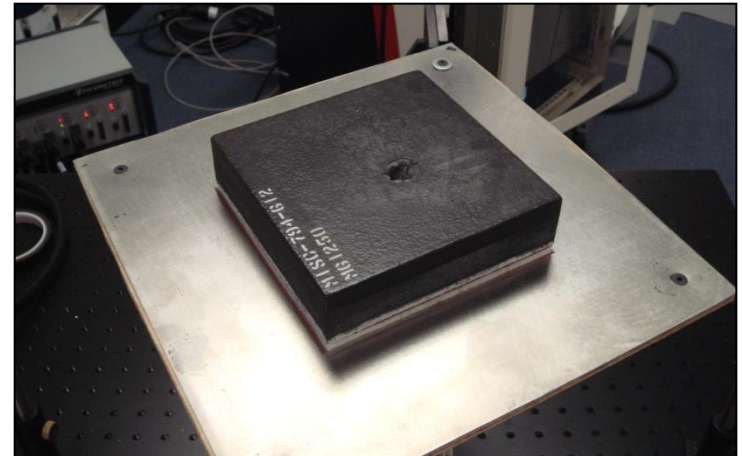
CT TD-THz Setup

THz Transmitter THz Receiver



TD-THz Controller

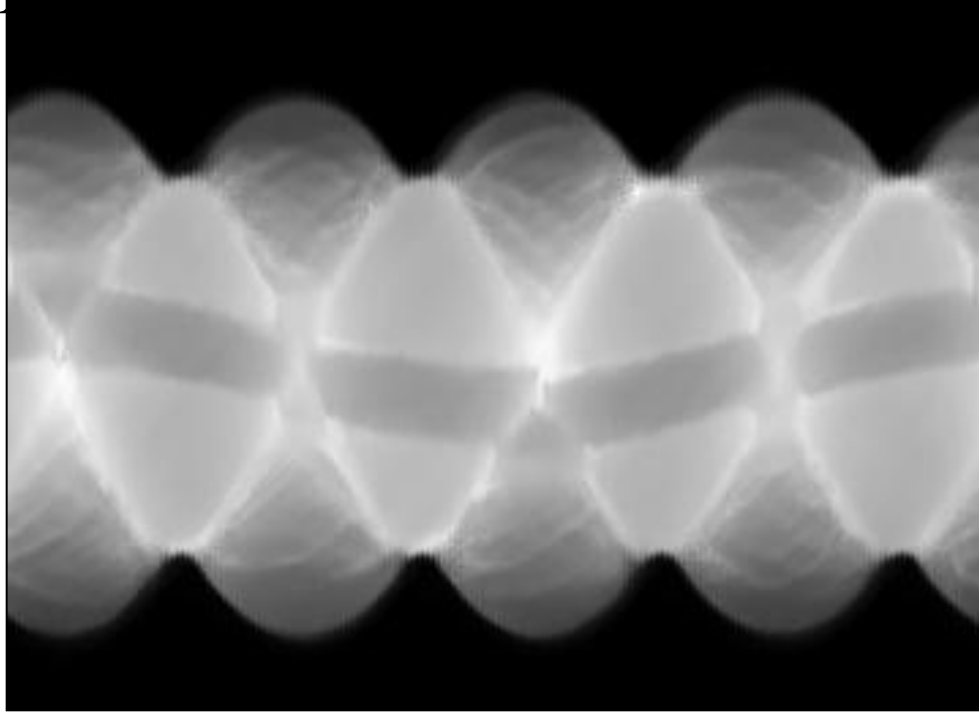
CT Gantry



TUFFI Tile on Rotation Mount

- TD-THz Transmission CT Sinogram Collection
- Beam Focused Through Side of Tile
- Path through tile is approx 6 in. to 8.5 in, depending on angle.
- Z-Axis is Height
- Collected 3 slices

Example Sinogram of TUFI TILE

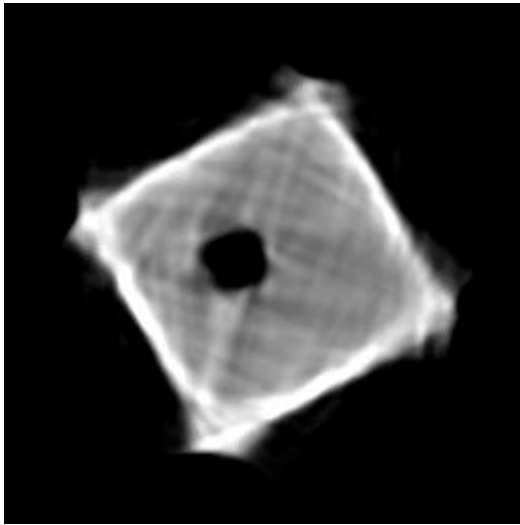


- Collected over 360 degrees
- Analysis is time-of-flight computed by centroid with a bandpass pre-filter between 0.3 and 0.8 THz

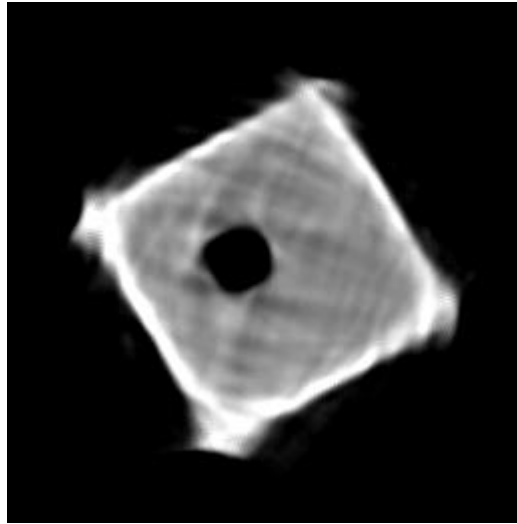
TUFI TILE

CT TD-THz Slice

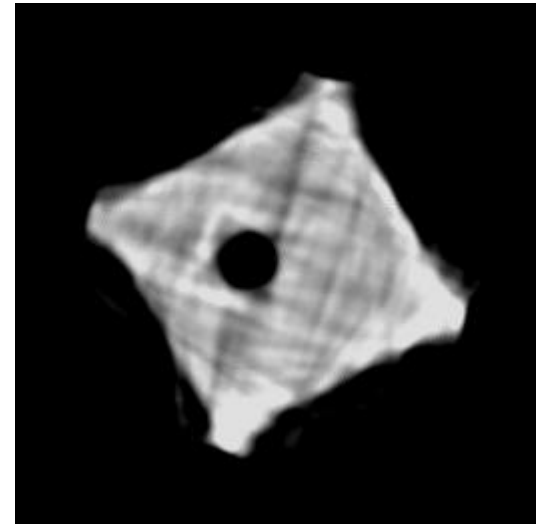
Reconstruction



Surface -5 mm



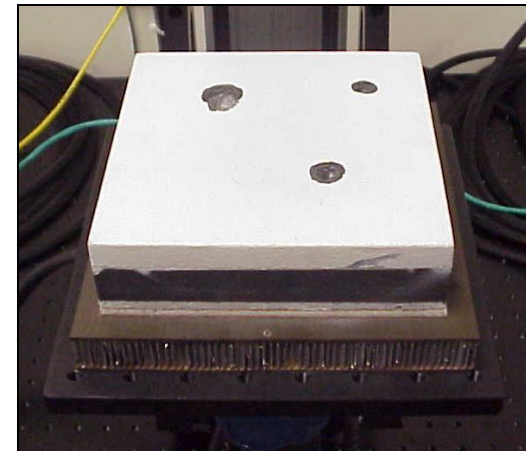
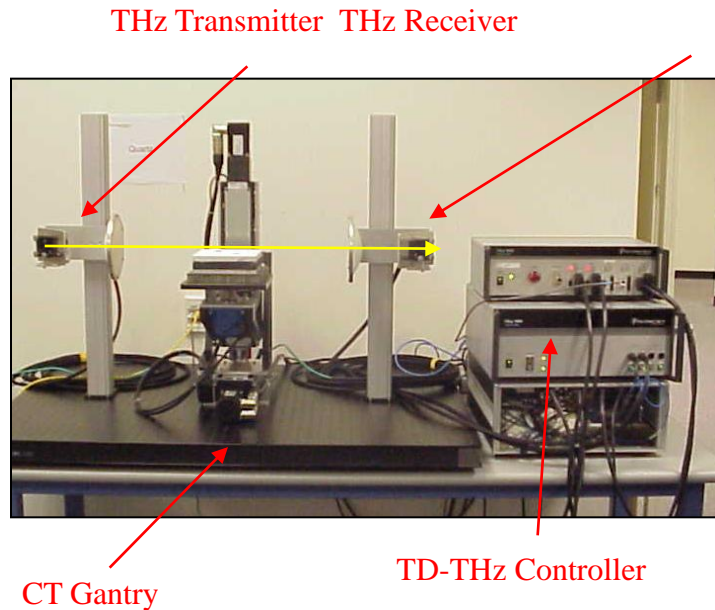
Surface -10 mm



Surface -15 mm

- Impact hole clearly visible in all slices with high contrast.
- Top to slices show higher density at edges due to glaze/ceramic overcoat. Not present on bottom half of tile.

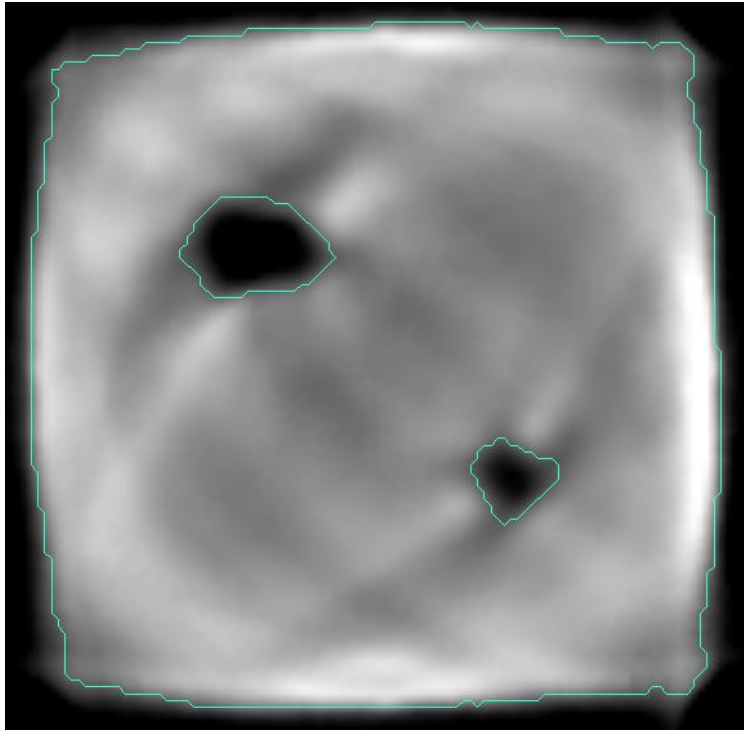
Phase II TD-THz CT Setup



TUFIT Tile on Rotation Mount

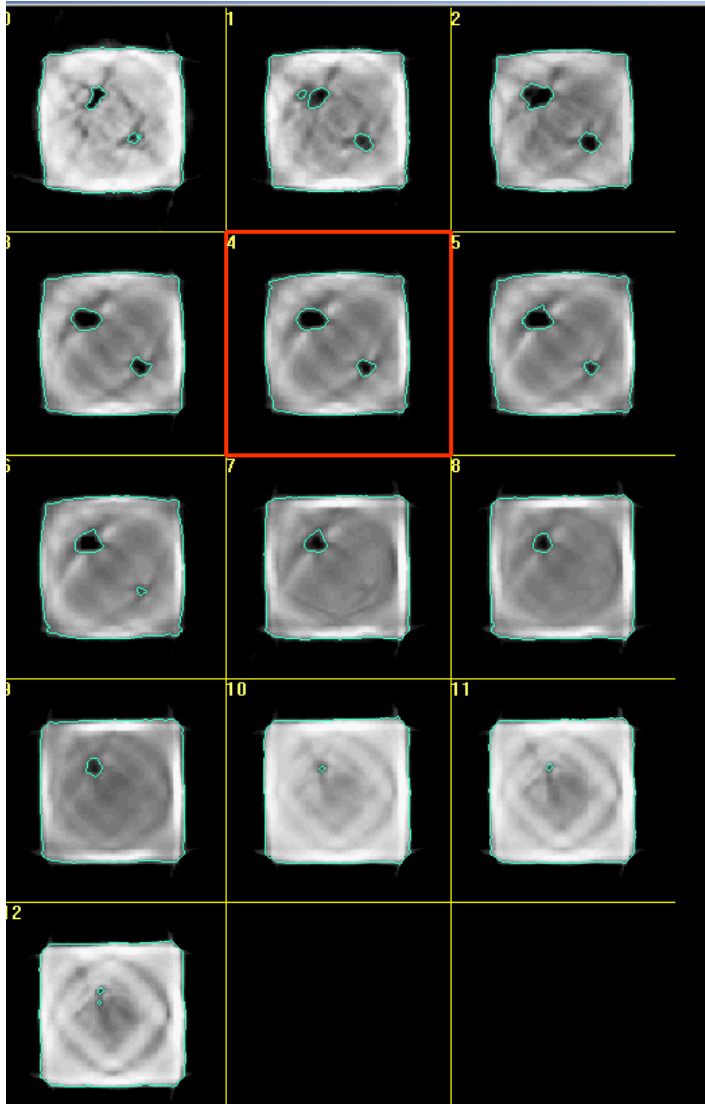
- TD-THz Transmission CT Sinogram Collection
- Beam Focused Through Side of Tile
- Path through tile is approx 6 in. to 8.5 in, depending on angle.
- Z-Axis is Height
- Collected 20 slices at 2 mm

Preliminary TD-THz CT Slice Reconstruction



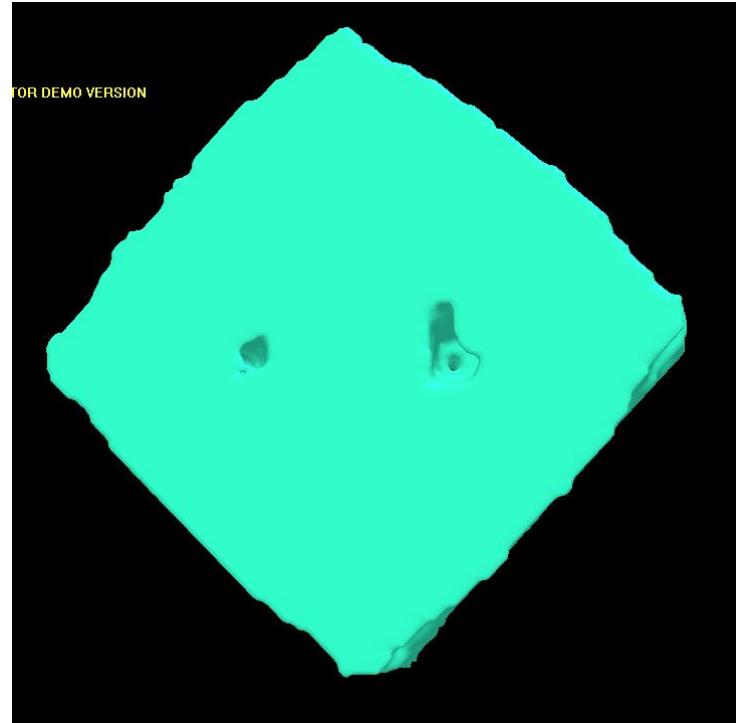
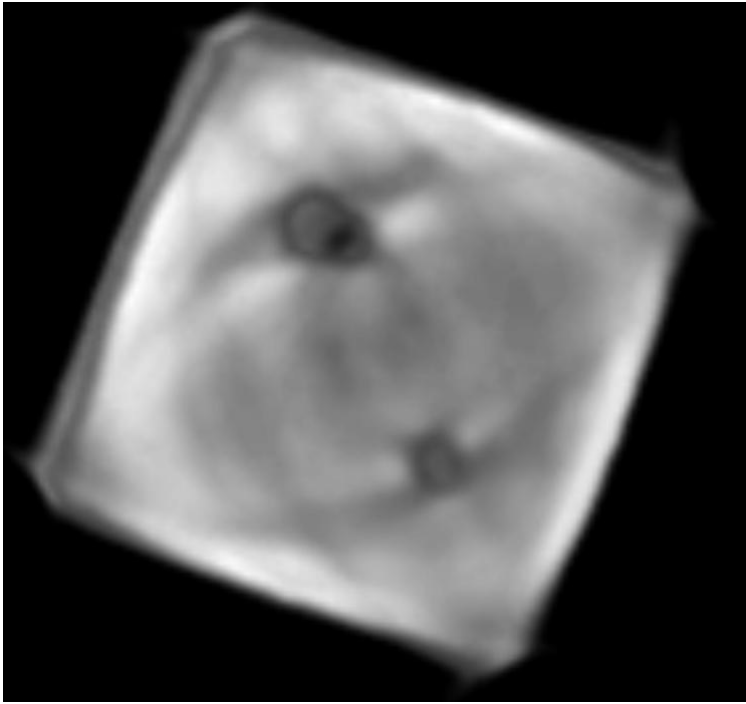
- Middle slice showing middle hole and deep hole
- Analysis is time-of-flight computed by centroid of the deconvolved TD-THz pulse. No bandwidth filter.
- Plan to reanalyze, excluding low frequencies to possibly improve resolution of small features.

Montage of Slices



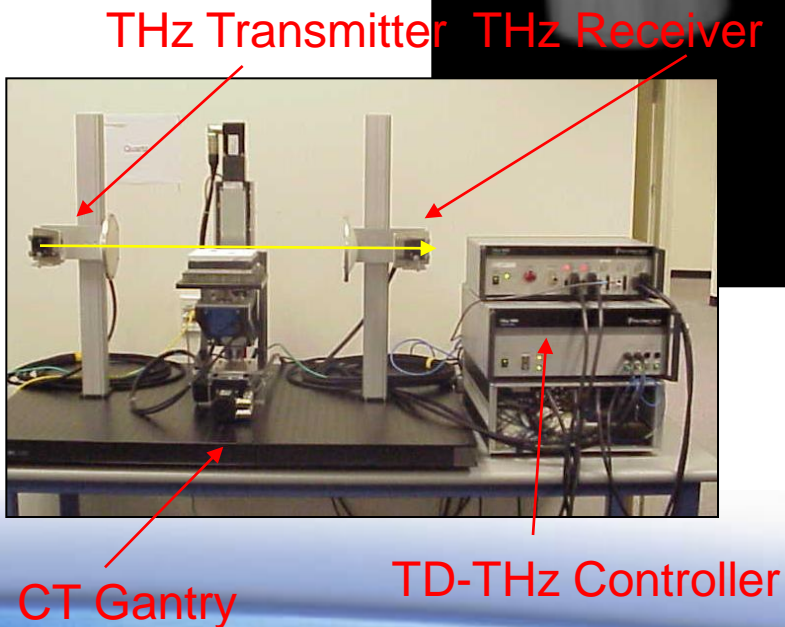
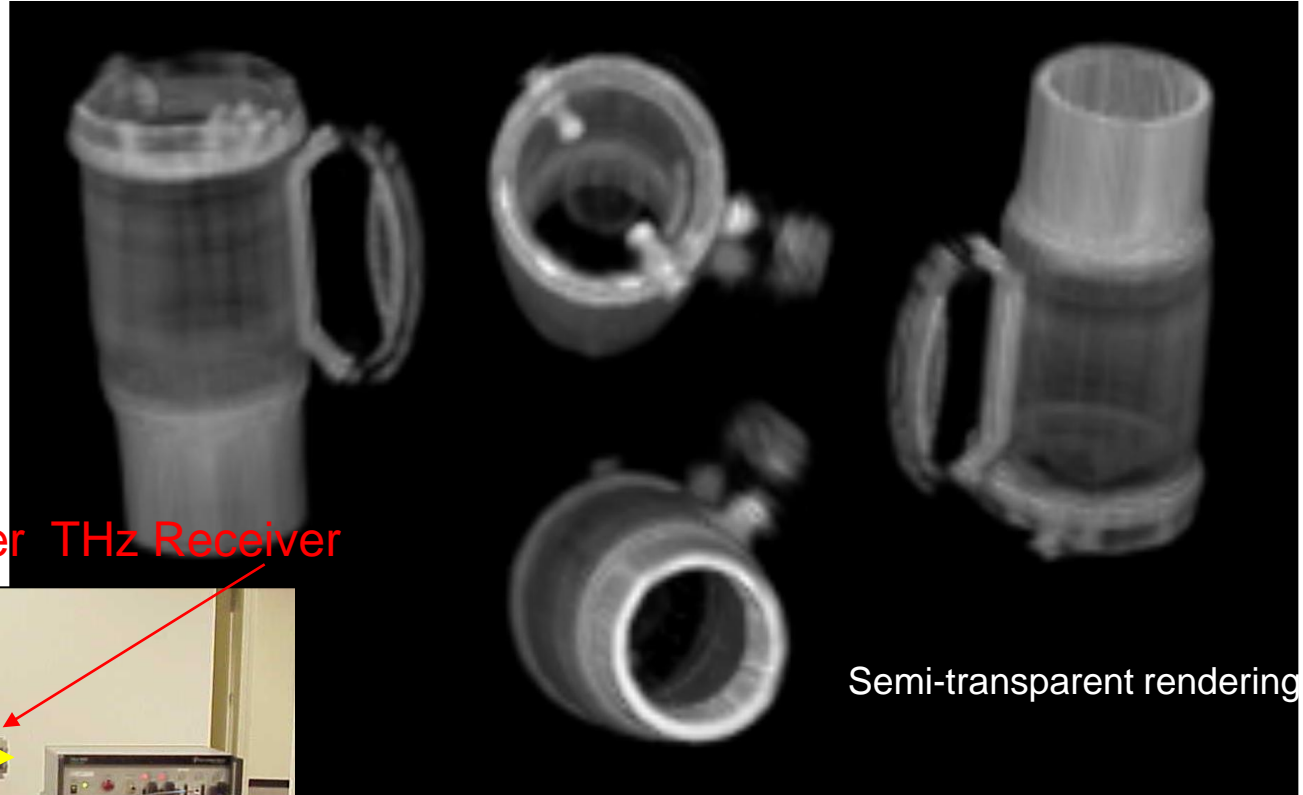
- Shows middle hole bottoms before deeper hole.
- Slice spacing is 2mm.
- Excluded the top and bottom 2 slices showed reconstruction artifacts due to the air and substrate. Developing and analysis to minimize.
- The shallowest hole is excluded due to these artifacts.

Volume and Surface Renderings



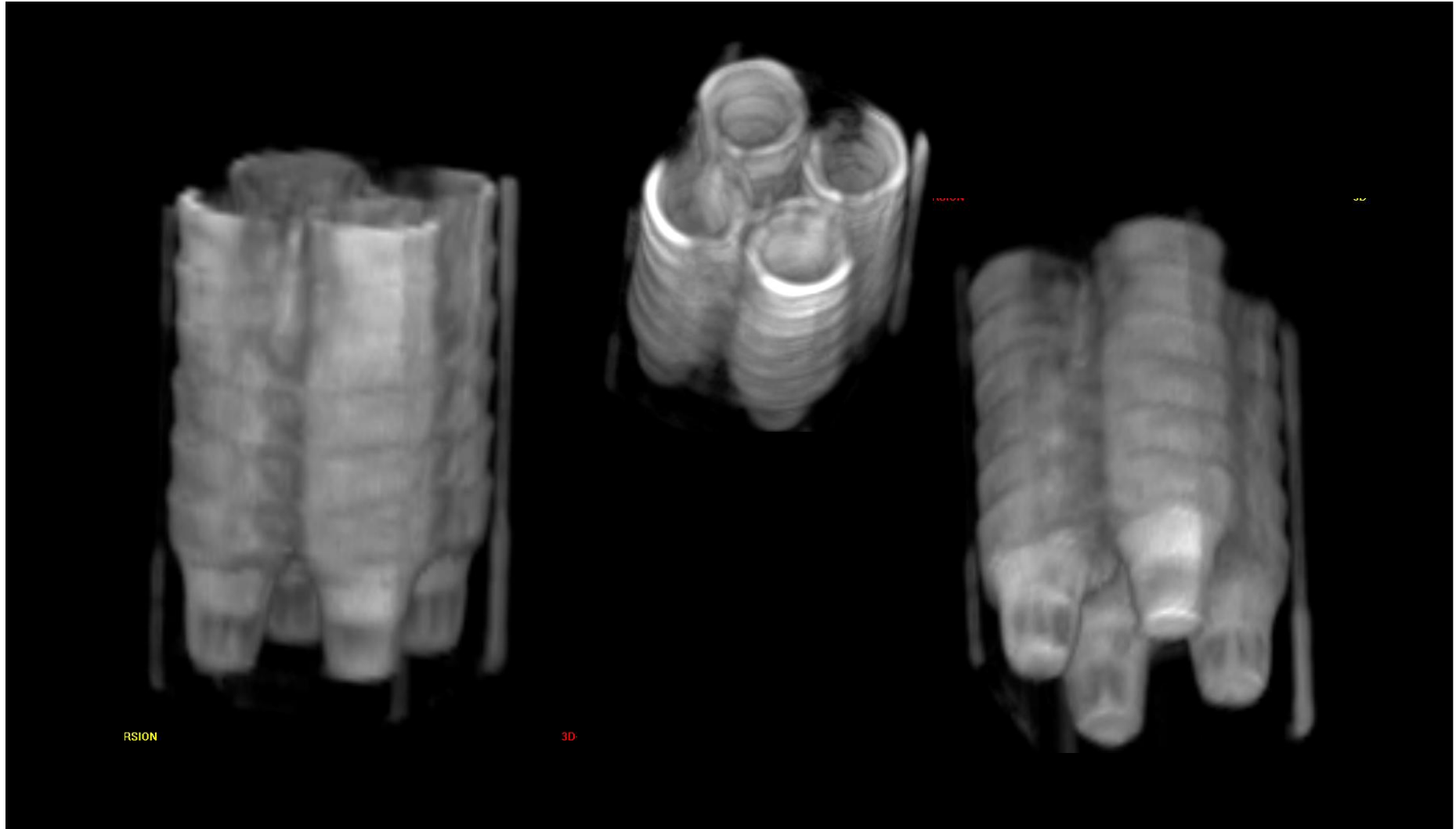
- Using 3D doctor (limited experience)

T-Ray™ Computed Tomography



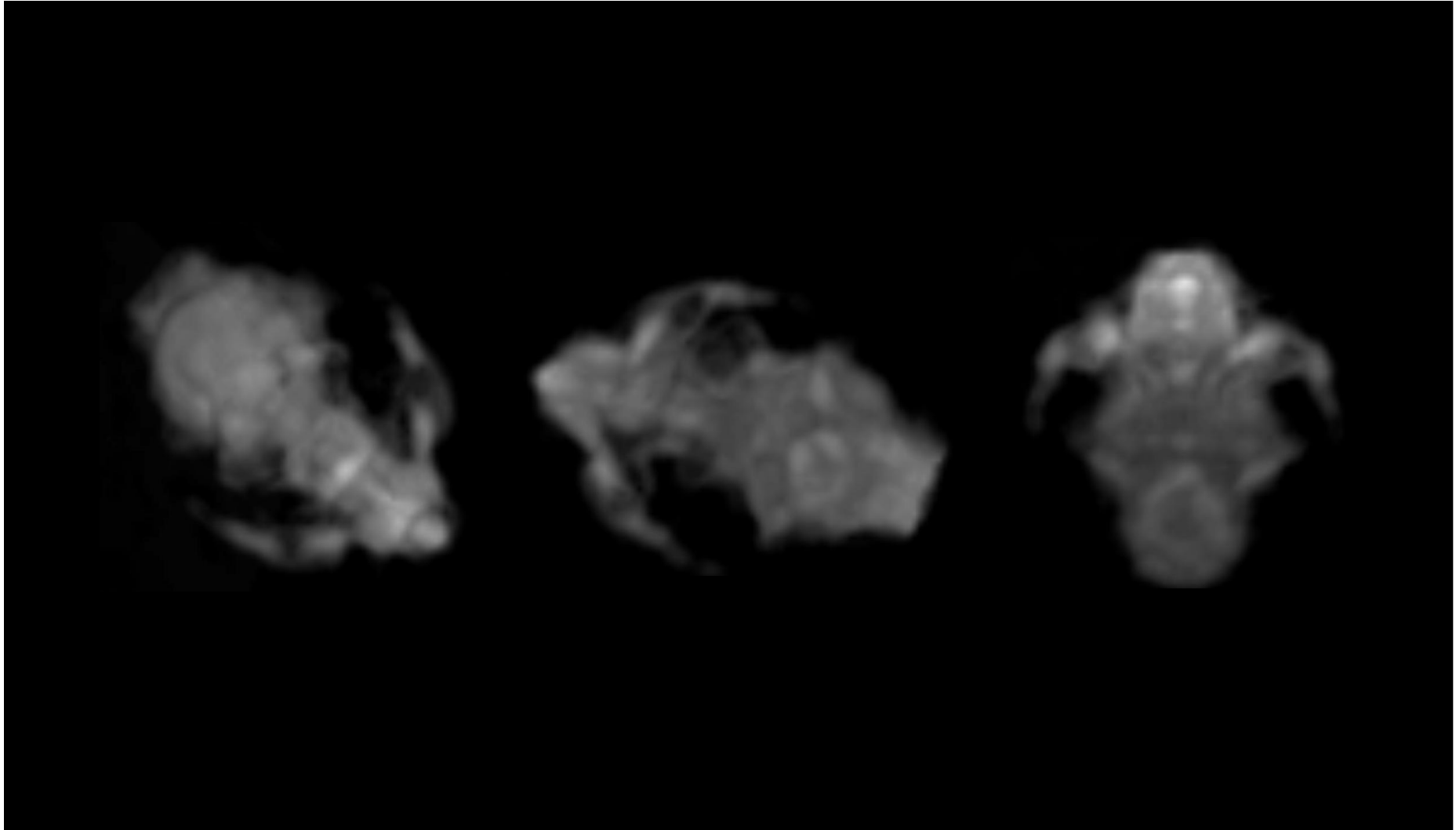
TD-THz CT Example

Box of ice cream cones



TD-THz CT Example

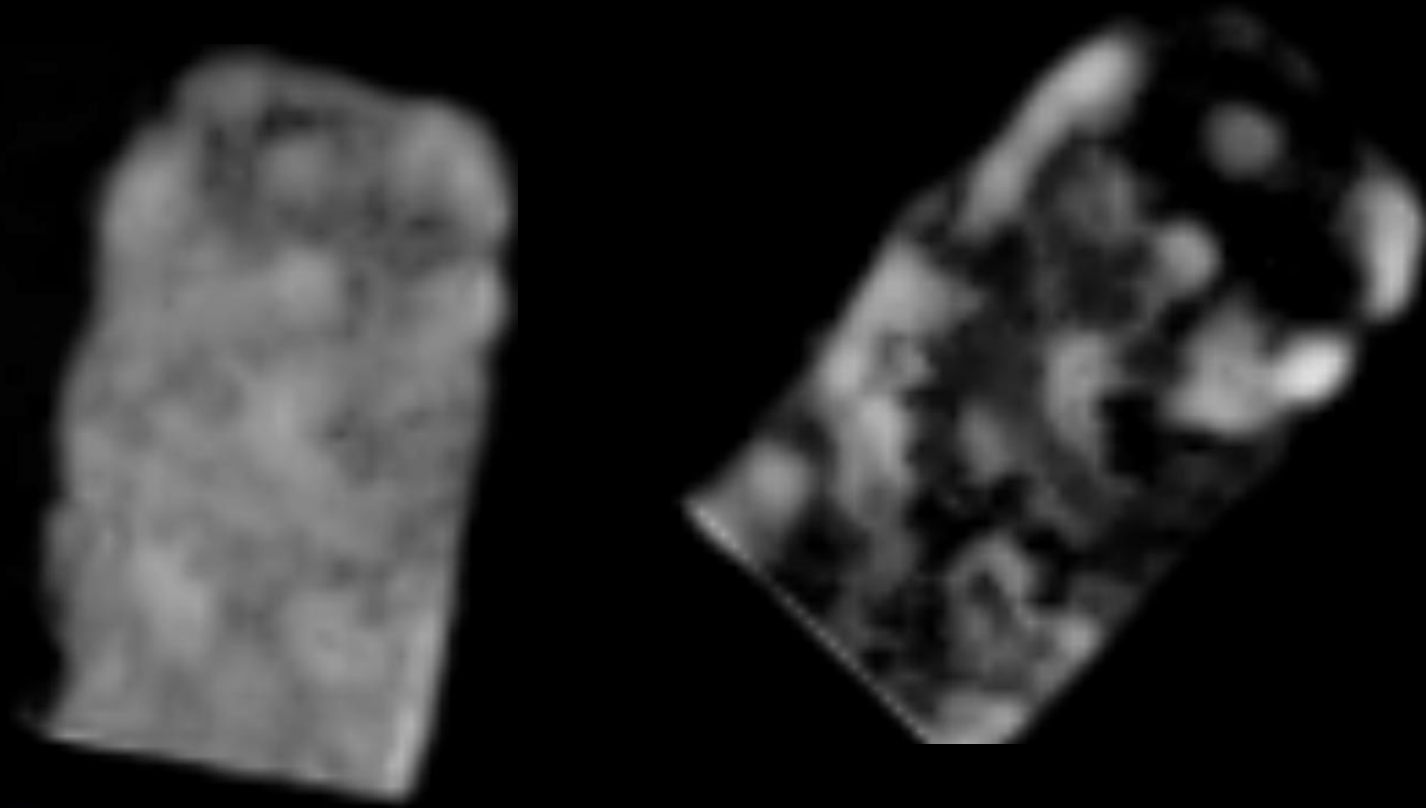
Cat Skull



TD-THz CT Example

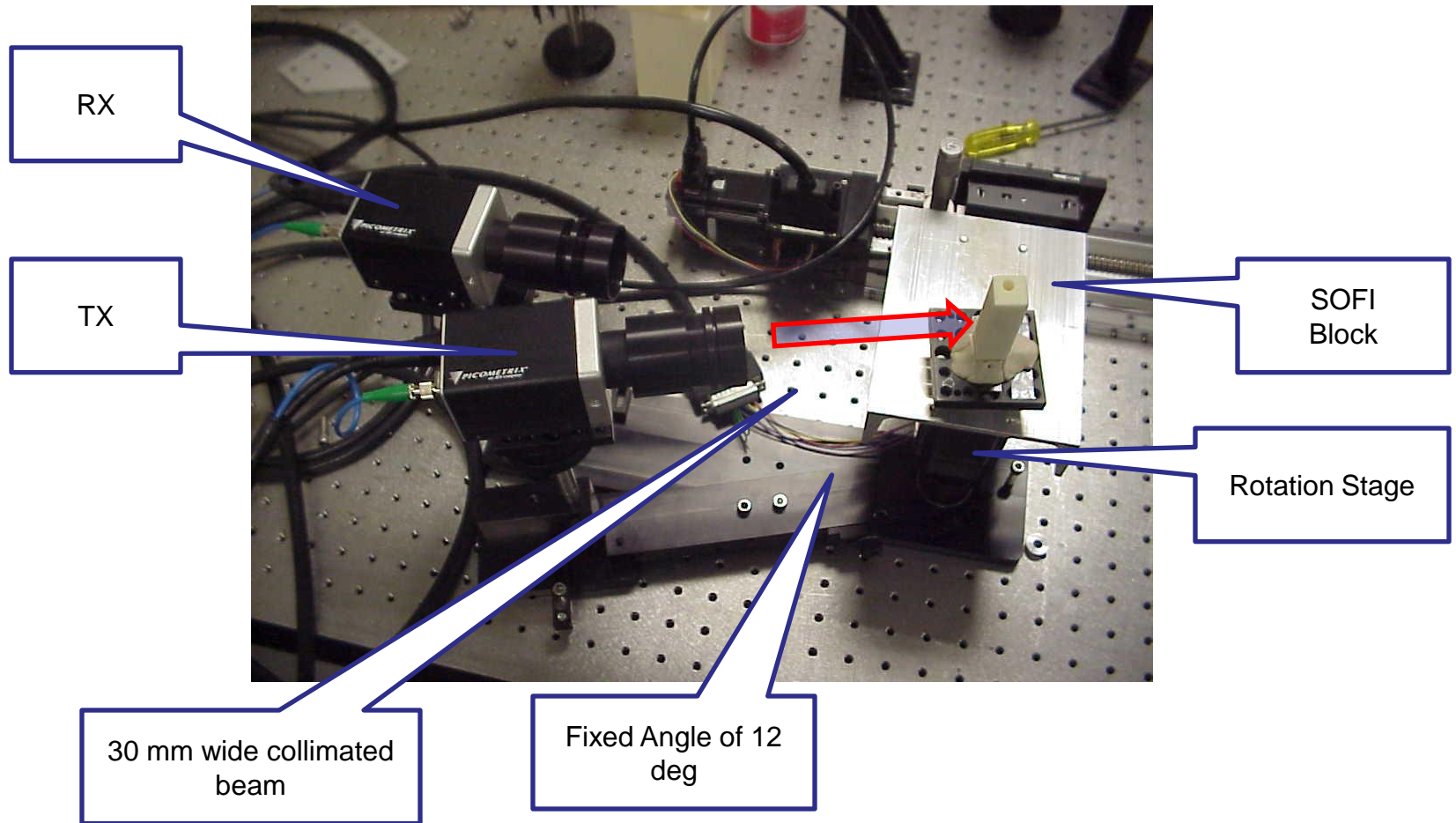
Honeycomb

(more transparent shows dead bees)

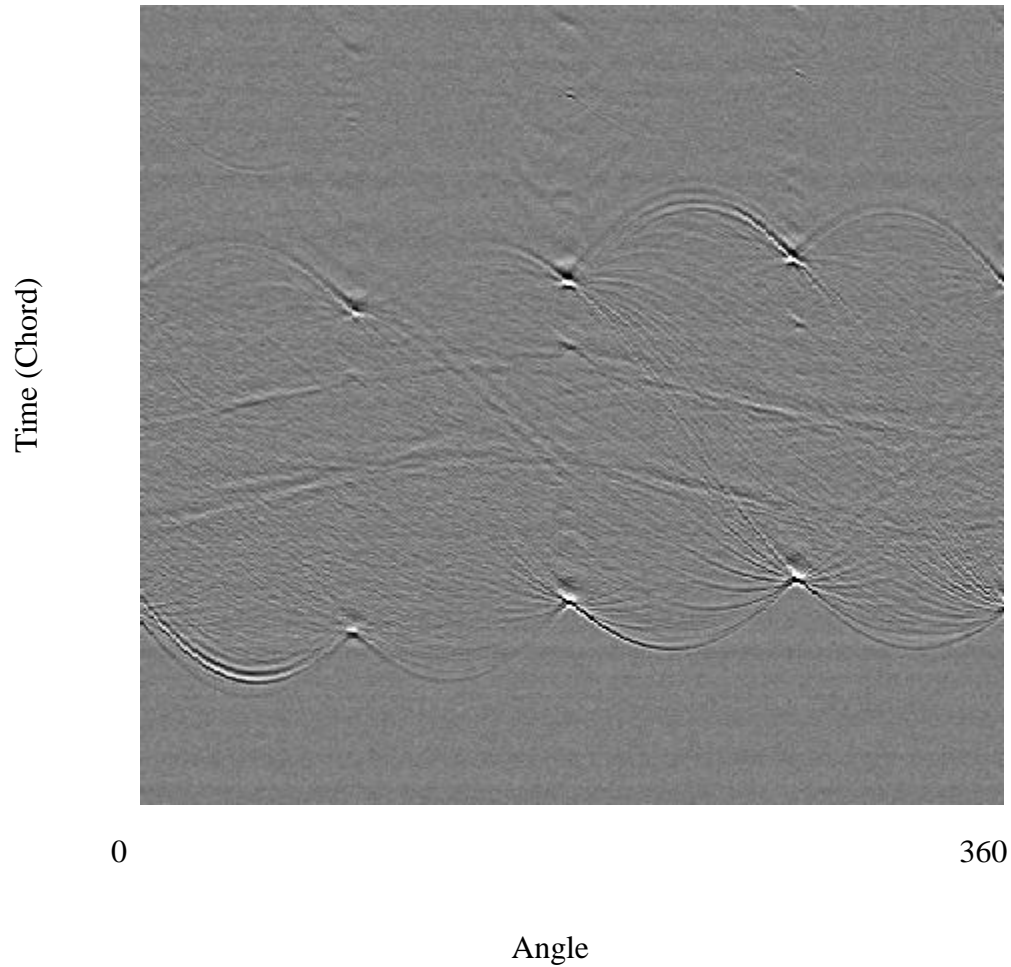


RSION

TD-THz Reflection Computed Tomography Setup

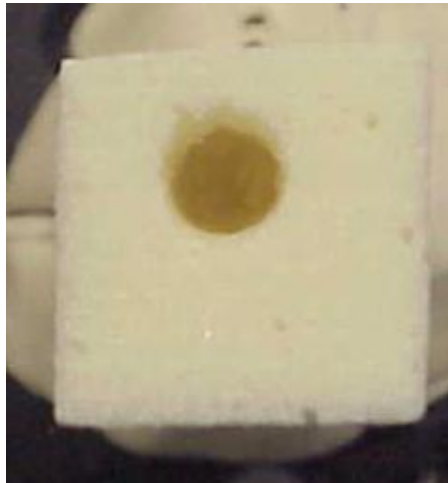


Reflected Wavefield (Sinogram)

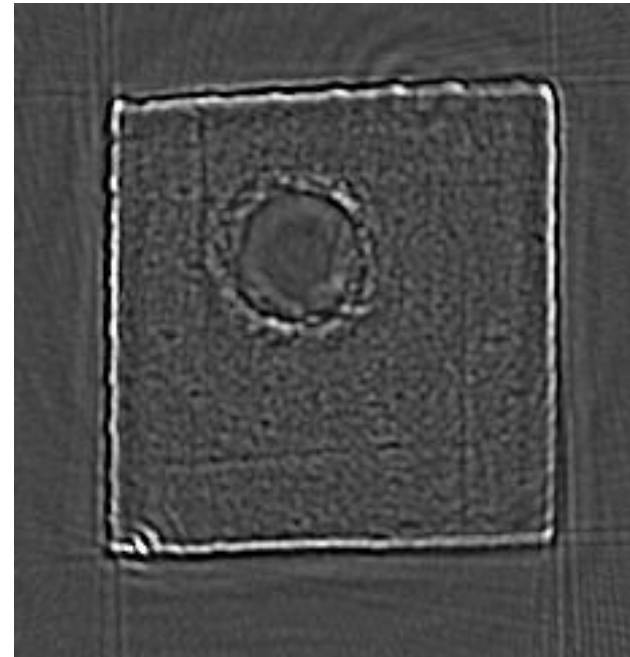


SOFI Block Reconstruction

Inverse Radon Transform/Filtered Back
Projection



Visible

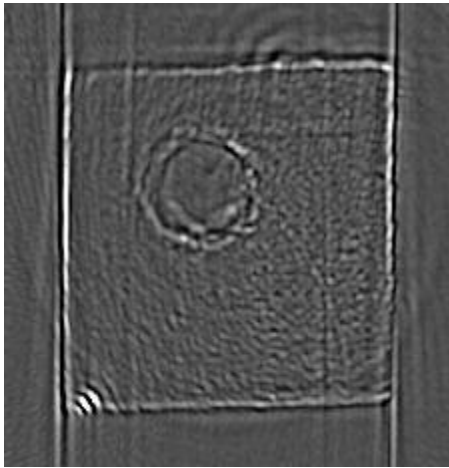


THz

Void bored in foam visible.

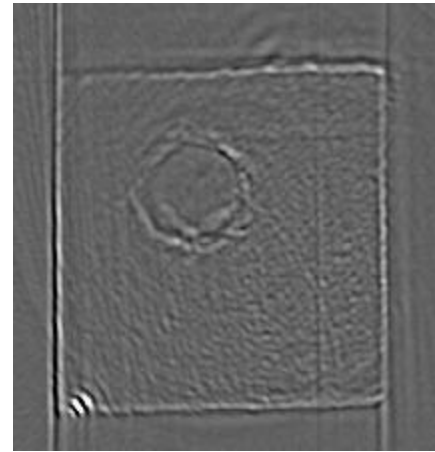
Single Sided Reconstructions

Inverse Radon Transform/Filtered Back
Projection



180 deg

(full single sided)



150 deg

(partial single sided)

Hand-Movable Real Time Imager

NDE and Imaging

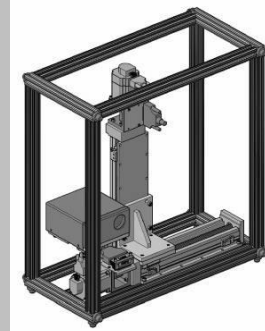
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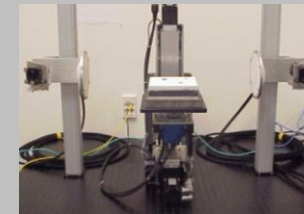
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Base System**



**T-Ray 4000®
Control Unit**
100 Hz and 1KHz



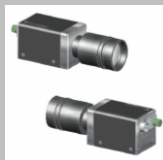
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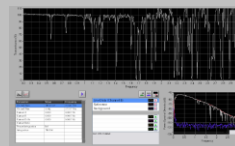
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**T-Ray® Transmitter
and Receiver**



**Spectroscopy
Station™**



**T-Ray®
Explorer™
Software**



T-Ray® T-Gauge™



New for 2010!

Industrial Online
Measurement

Imaging Speed

Limitations of Gantry

- Maximum pixel rate typically limited by waveform acquisition rate
 - Standard option: 100 Hz
 - High speed option: 1 kHz
- Increase the number of sensors
- Maximize the scanning rate
- Collect less than all the pixels
 - Advanced algorithms and modulators
- Develop alternative to traditional single sensor X-Y raster scan gantries

T-Scanner™

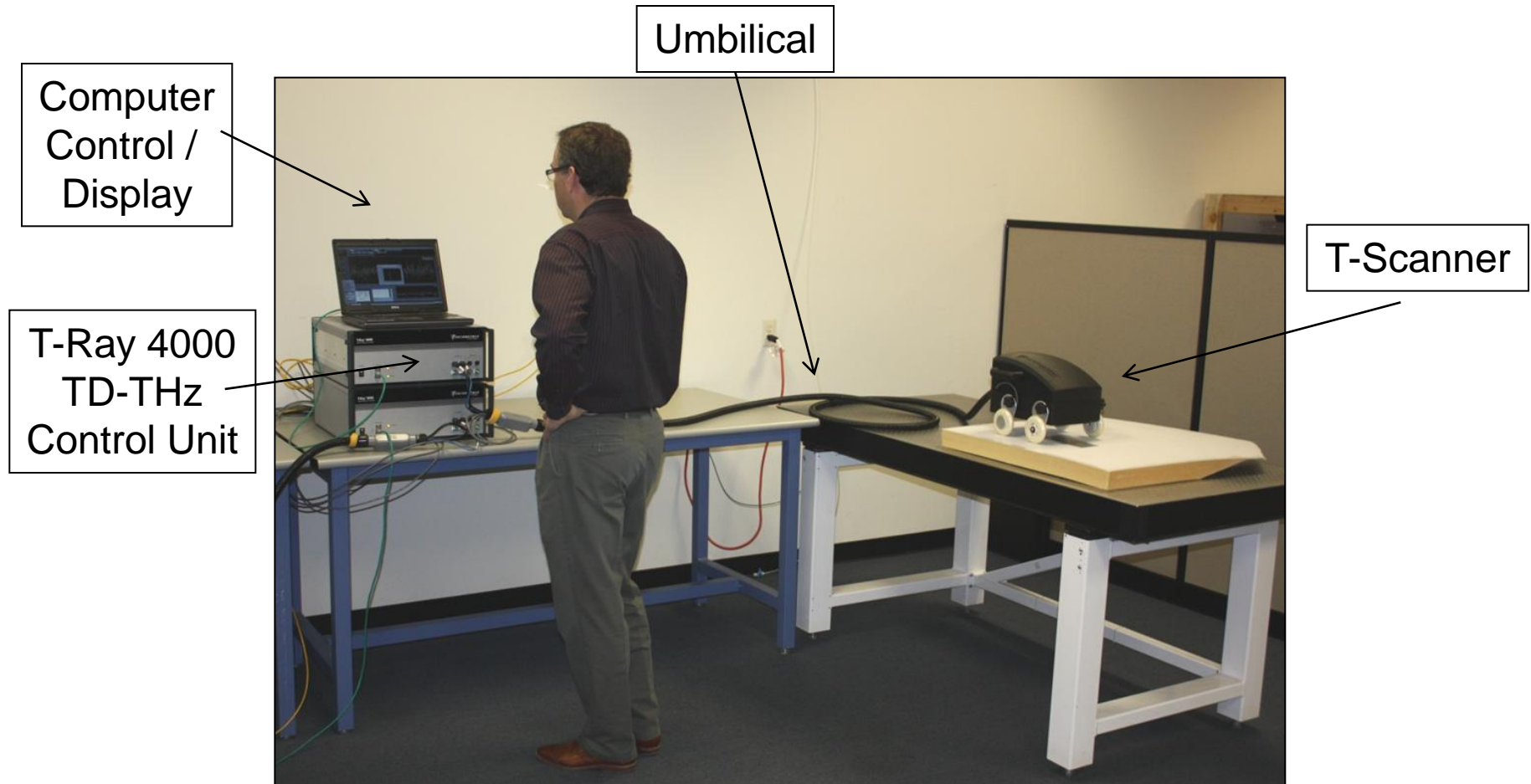
Portable High Speed Reflection Imager

- 150 mm (6 in.) wide scan
- 2 mm spot size
- Scan rate up to 15 Hz
- Video rate B-Scan
- Push by hand to sweep out C-Scan



- Trade-off between scan rate, waveform acquisition speed and pixel size
- Current controllers are designed to collect waveforms at either 100 Hz or 1000 Hz.

T-Scanner™ Setup

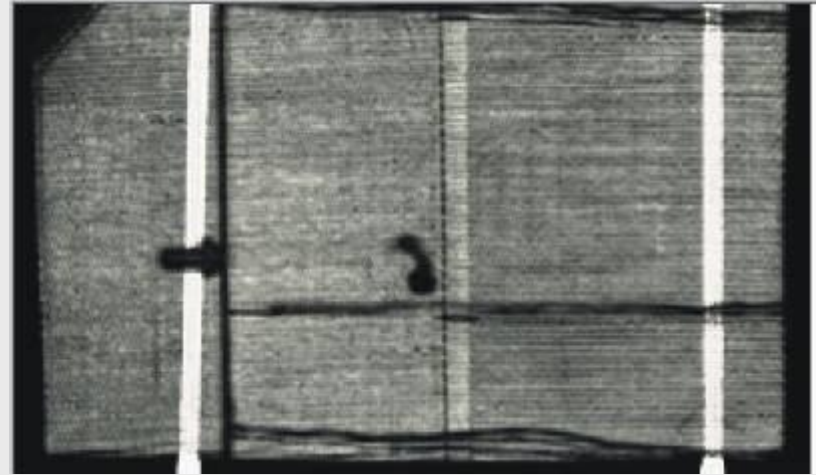


Delamination and Water Intrusion

Construction Example



Weather Radome



**Radome Panel
With Water Intrusion**

Water intrusion into composite laminate panel degrades radar performance.
Current solution: Tap Testing

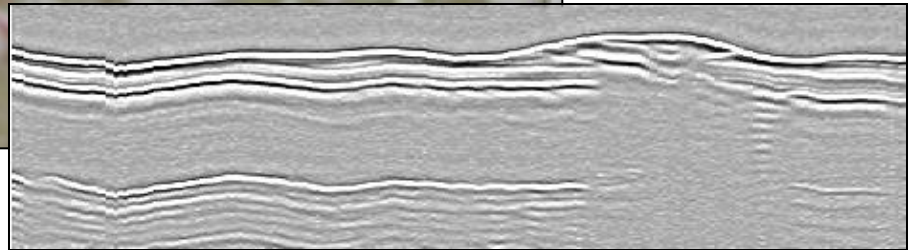
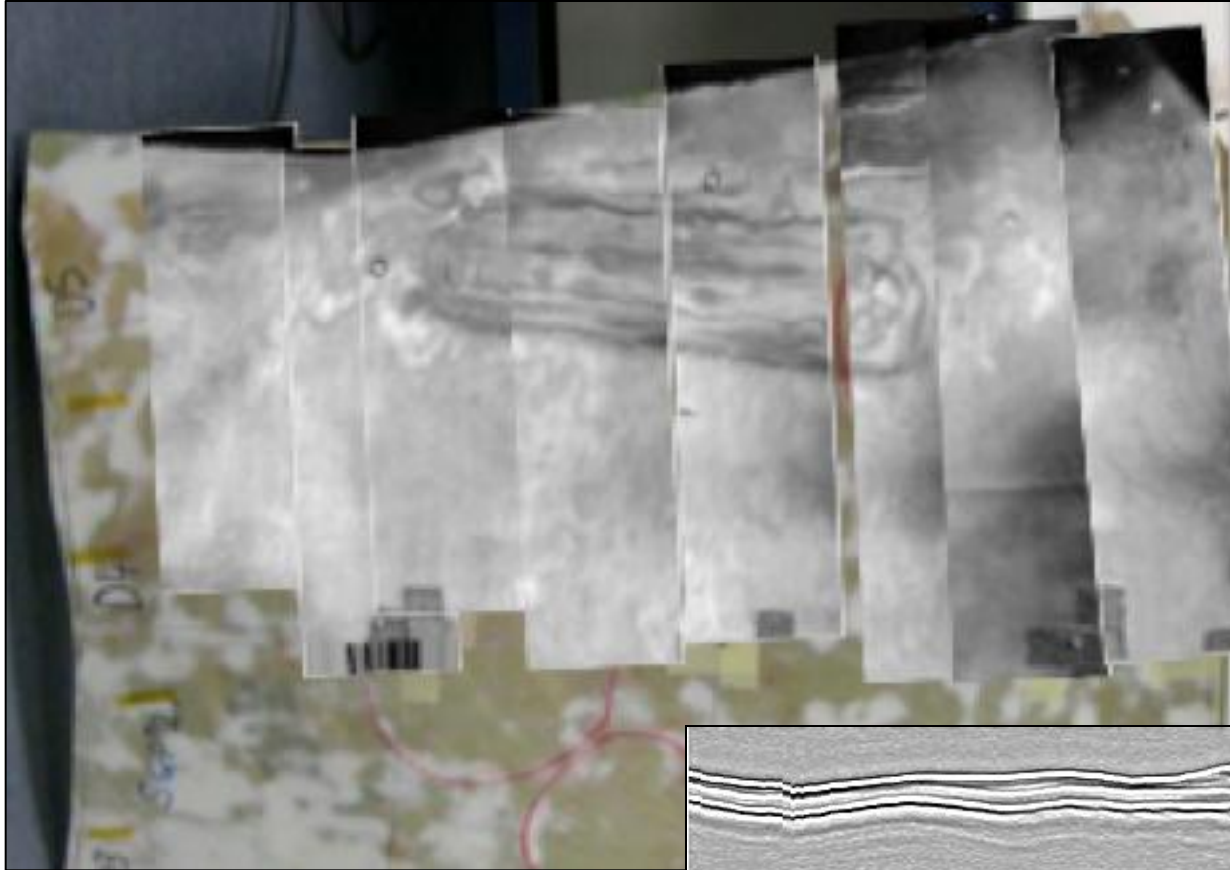
Ground-Based Radome Scan



- Scan width 150 mm
- Maximum rate 15 Hz
- Maximum pixel rate 800 pixels per second

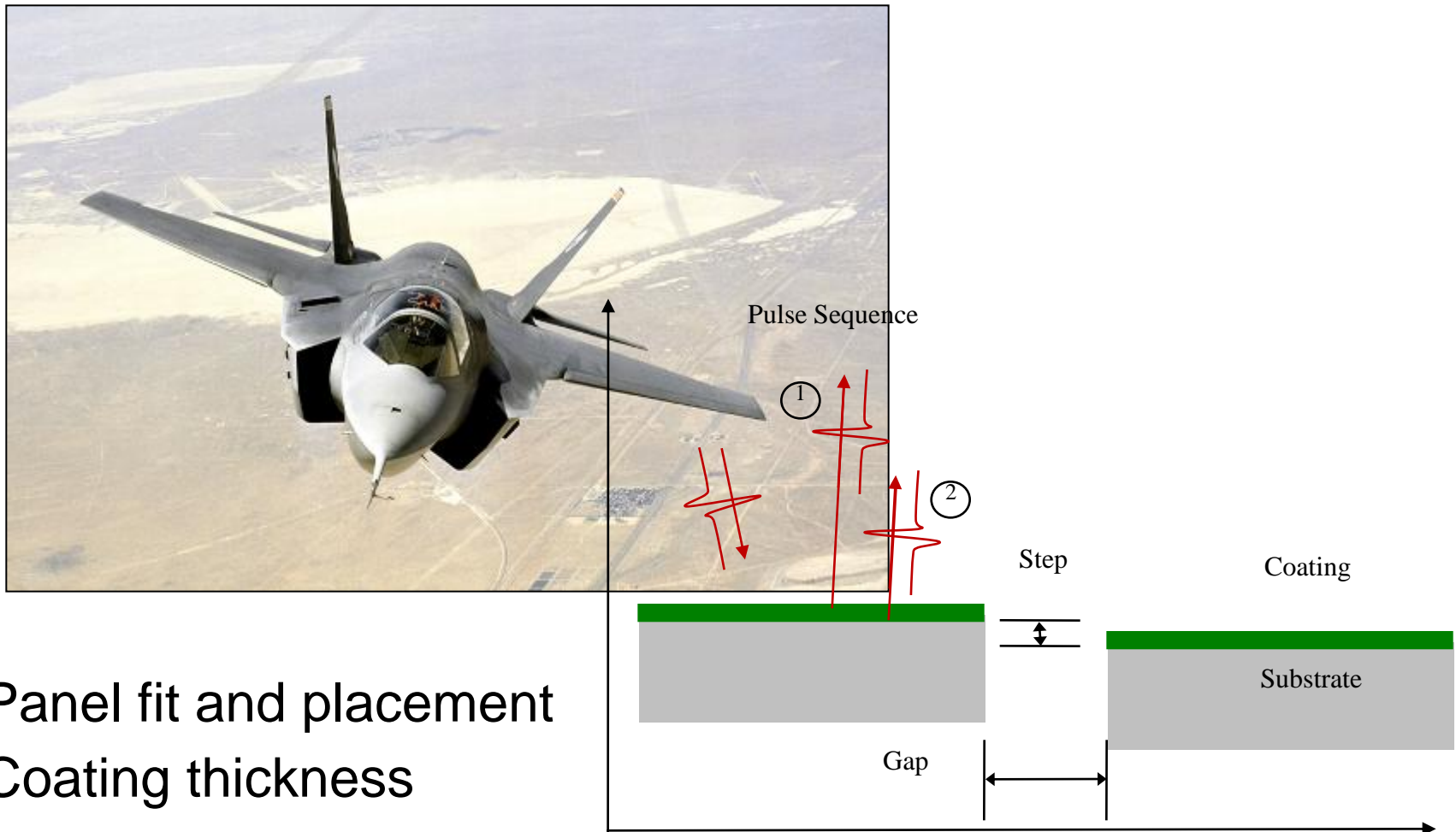


Scan of C-130 Radome



- Large defect identified
- Plan images and cross-sections can be produced

F-35 Manufacture and Repair



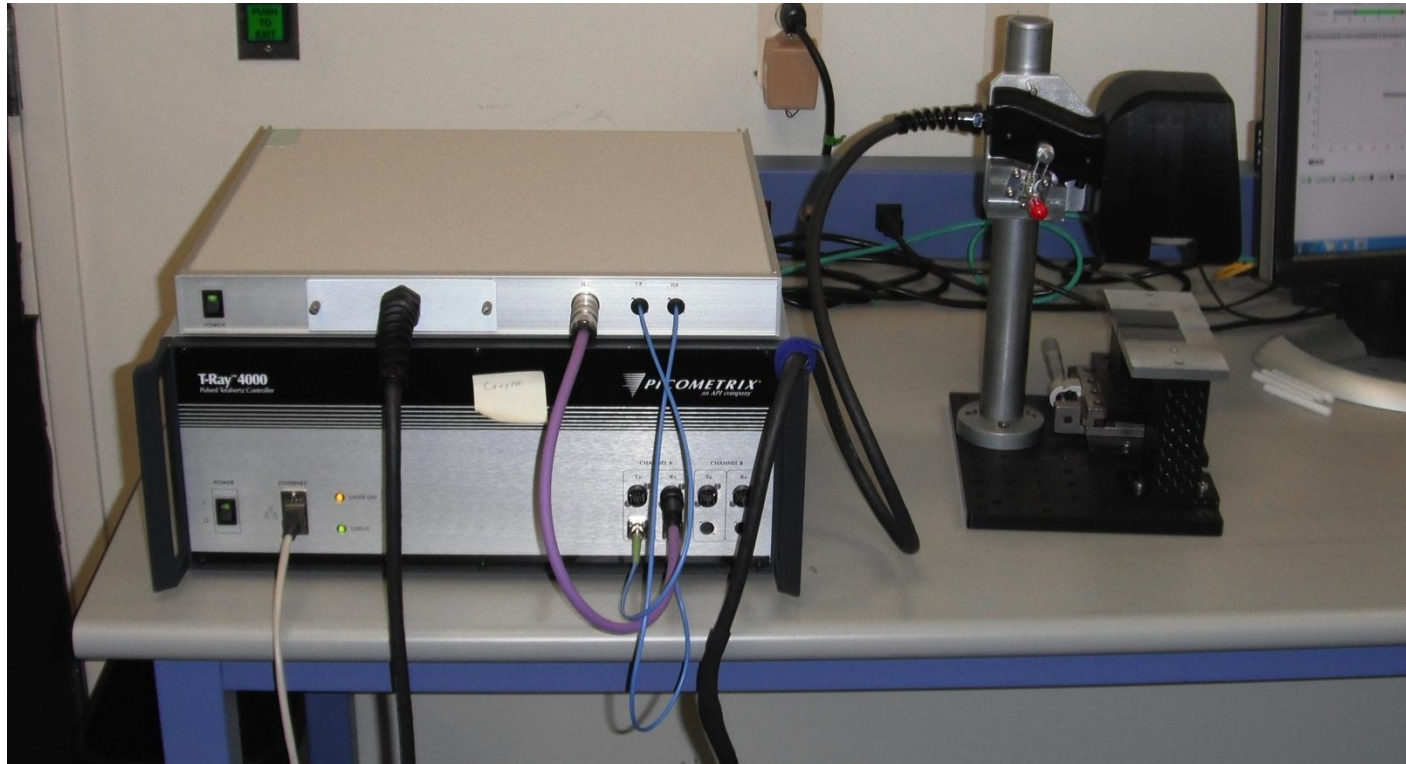
- Panel fit and placement
- Coating thickness
- Explosive environment

This work sponsored by the Air Force Research Laboratory (AFRL).

Phase II TD-THz Step/Gap Measurement Prototype

Hand-Held Interface Unit

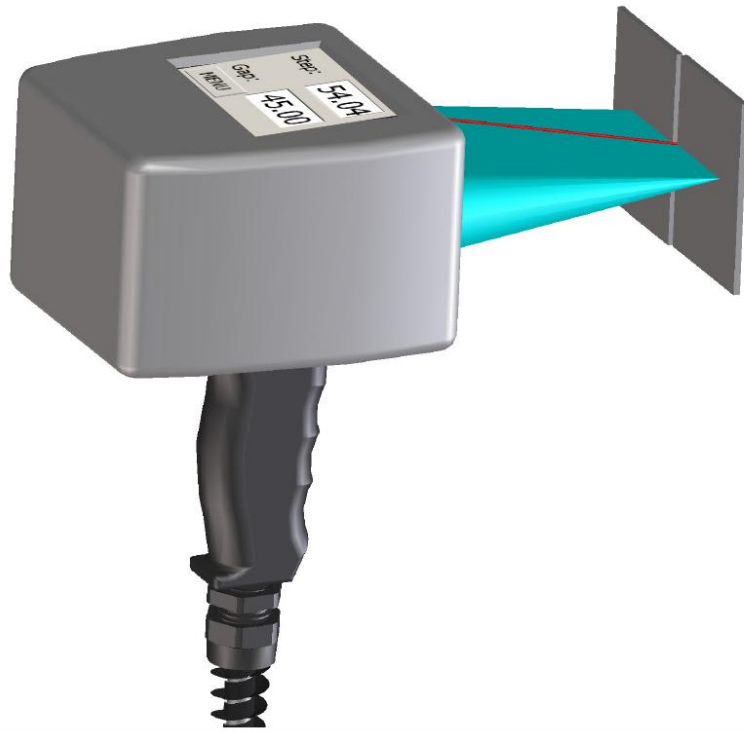
Hand-Held Scanner



T-Ray 4000 Controller

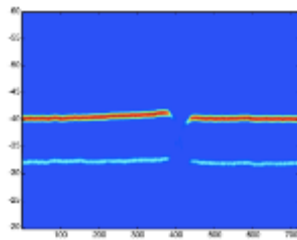
Adjustable Step/Gap
Testing Jig

Phase II hand-held T-Ray 4000 plug-in sensor



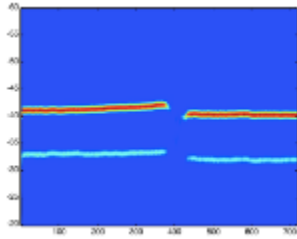
- Line-scan width 3 in.
 - Gap > 500 mils
 - Step 0 to > 250 mils
- Stand-off approx. 3 in.
- 4 to 10 B-scans per second
- Laser projection reticule aids operator positioning
- 3.5 in. high, 5.25 in. wide, 6 in. long (handle 4.2" high)
- 240 x 320 pixel backlit color LCD touch-screen, 3.78" diagonal
- 15 m umbilical
- Weight 3 lbs.

Panel offset (step and gap)

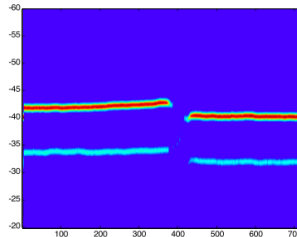


Step

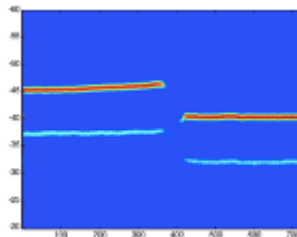
0 mils



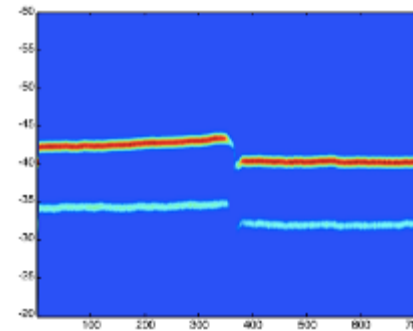
5 mils



10 mils

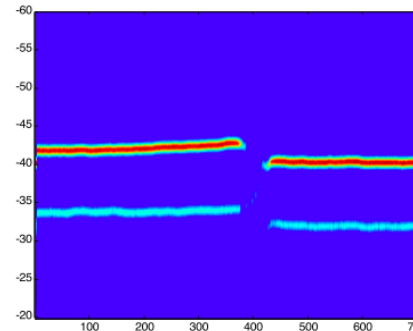


30 mils

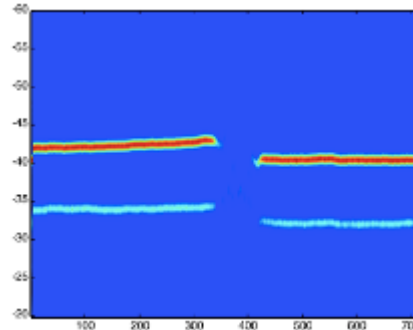


Gap

100 mils



250 mils

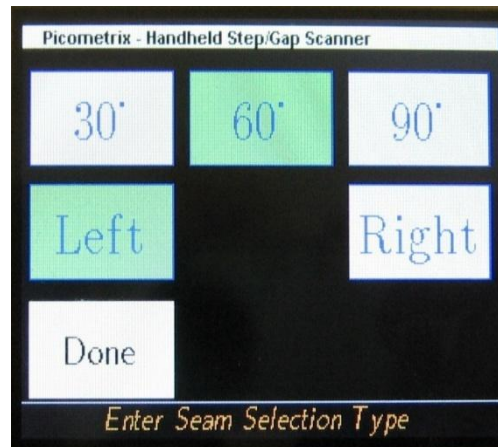
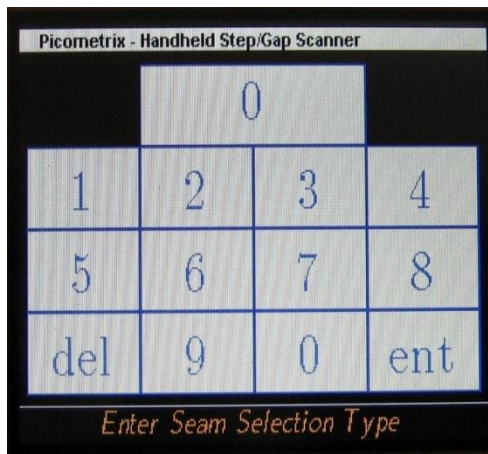
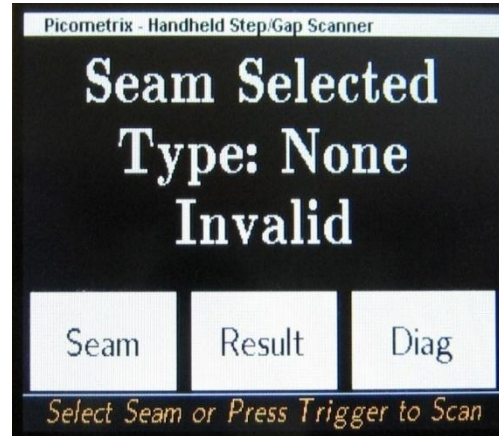
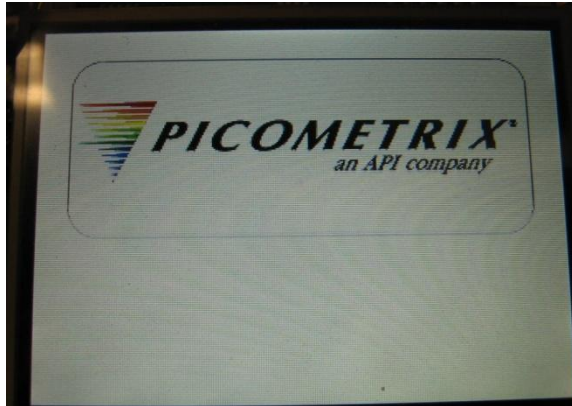


400 mils

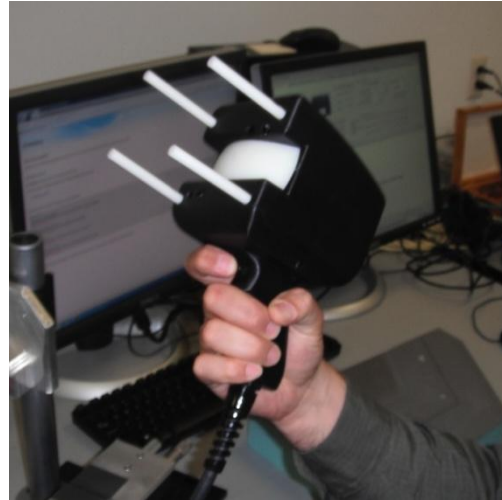
THz can look through the coating to the underlying metal to adjust fit
Also deployed in the paint booth to control the thickness

This work sponsored by the Air Force Research Laboratory (AFRL).

Making A Measurement Touchscreen Seam Selection



Making A Measurement Scanning and Results



T-Ray 5000 platform



- Touchscreen
- Internal processing
- Integrated umbilical
- 35 lbs
- 0 – 50 °C

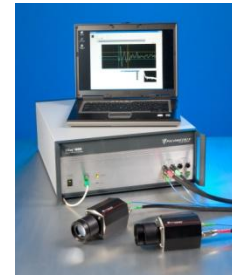
Proposal No. X5.04-8154 - Miniaturized Time Domain Terahertz Non Destructive Evaluation Instrumentation for In Orbit Inspection of Inflatable Habitats and Thermal Protection Systems

PI: Dr. David Zimdars
Picometrix LLC., Ann Arbor, MI

Identification and Significance of Innovation

- Picometrix's time-domain terahertz (TD-THz) non-destructive evaluation (NDE) systems can be used to inspect space flight structures such as inflatable space habitats, thermal protection systems (TUFI-type tiles, SOFI TPS), and other components for voids, disbonds, and damage such as tearing and micro-meteorite impact.
- However, the COTS TD-THz control unit is too large and heavy and require too much electrical power for space based use.
- The Phase II project will develop and construct a TD-THz reflection tomography NDE instrument < 1/3 the mass and volume of the COTS control unit.

Expected TRL Range at the end of Contract: Phase I 3, Phase II 6-7



Current 19 inch rack mount
TD-THz Control Unit, 55 lbs

**Shrink volume, mass,
Electrical power by better than 1/3**



Phase II
Compact Control
Unit, <15lbs



+ Handheld
Imager

SBIR Project

Technical Objectives and Work Plan

Phase II Feasibility

- Construct a higher efficiency all-in-one TD-THz transceiver which reduces the laser optical drive requirements from the control unit based on the Phase I design.
- Construct a compact all-fiber-optic chirped fiber Bragg grating group velocity dispersion precompensator to replace the macroscopic opto-mechanical GRISM (grating/prism) design used in the COTS control unit based on the Phase I design
- Reconfigure the laser optical drive subsystem design into a miniaturized all-in-one power stabilized unamplified femtosecond fiber laser/chirped fiber Bragg grating GDC/fiber optic delivery.
- Construct and deliver a prototype compact TD-THz reflection tomography NDE instrument < 1/3 the mass and volume of the COTS control unit.

NASA and Non-NASA Applications

- In-space inspection of TPS, TUFFI, SOFI, and inflatable habitats.
- Inspection of composite aerospace components during manufacture and after aging.
- Material examples include ceramics, foams, Kevlar, Zylon, glass, and other non-conductive polymer matrix composites.
- Automotive composites, transmission and clutch plates, pipe insulation, circuit boards, homeland security – packages, mail, luggage.

Firm Contacts

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 dzimdars@picometrix.com

NON-PROPRIETARY DATA

T-Gauge™ for Industrial Measurement

NDE and Imaging

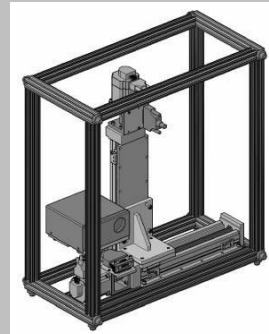
Imaging Station™



Motion Controller



Custom Gantry

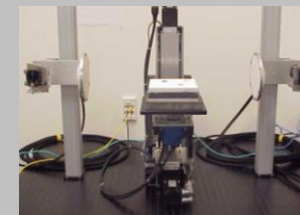


T-Scanner™



New for 2010!

T-Ray® Computed Tomography



New for 2010!

NDE and Imaging

Lab and Custom Configured R&D

T-Ray 4000® Base System



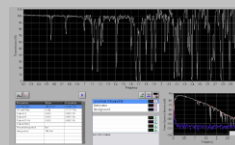
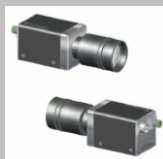
T-Ray 4000® Control Unit
100 Hz and 1KHz



Spectroscopy Station™



T-Ray® Transmitter and Receiver



T-Ray® Explorer™ Software



T-Ray® T-Gauge™



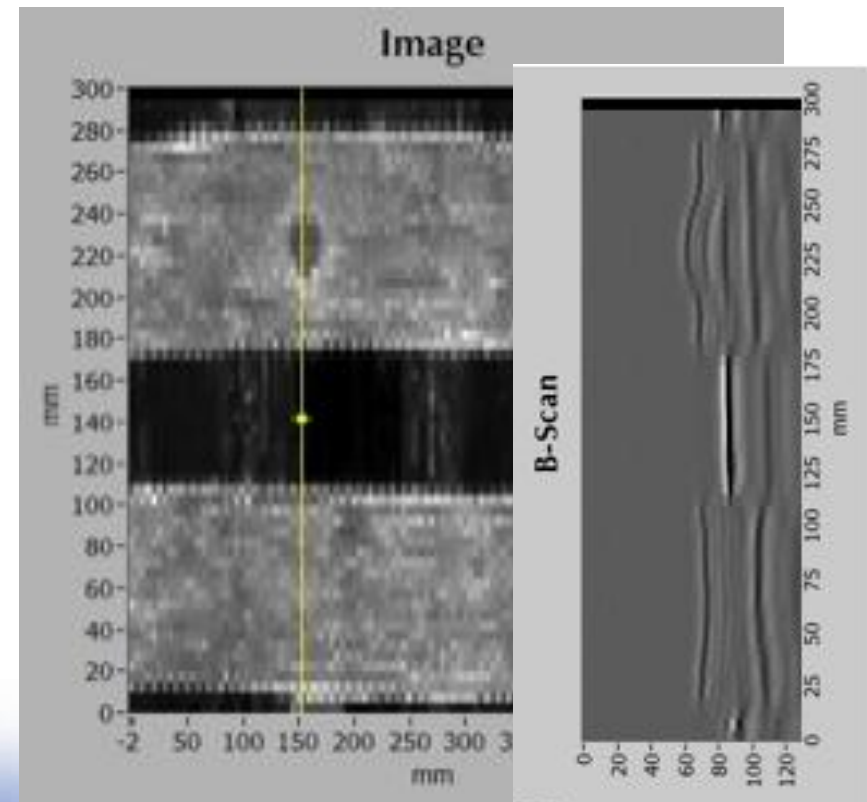
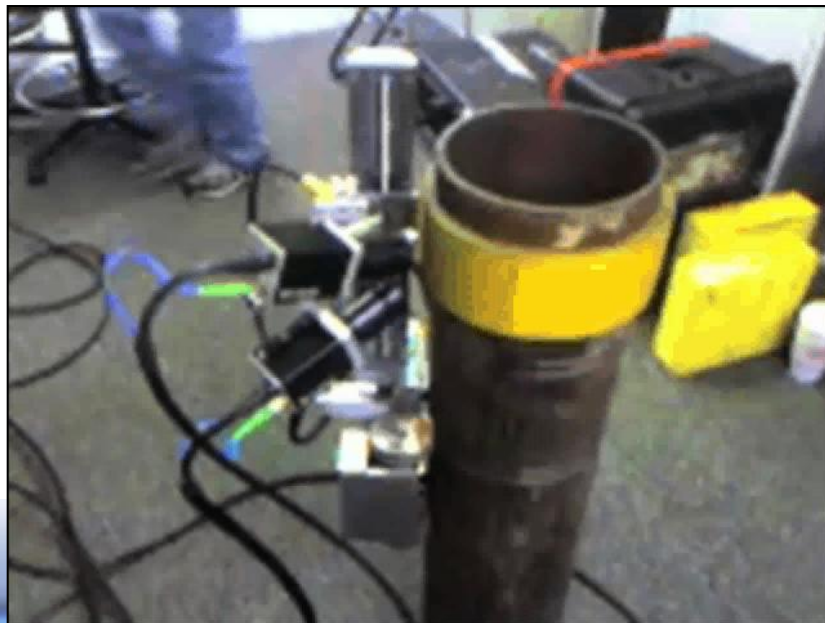
New for 2010!

Industrial Online
Measurement

Nondestructive Testing of Pipeline Repairs



- Petrochemicals
 - Pipe patch inspection
 - Extends lifetime



Extruded Material Manufacturing Plant



Two layer laminate with
cloth reinforcement

No method to measure
second layer thickness



← Nuclear gauge
— total thickness only

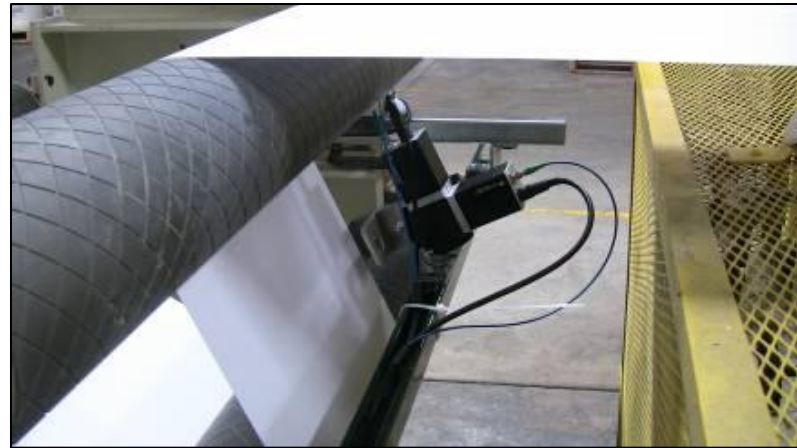
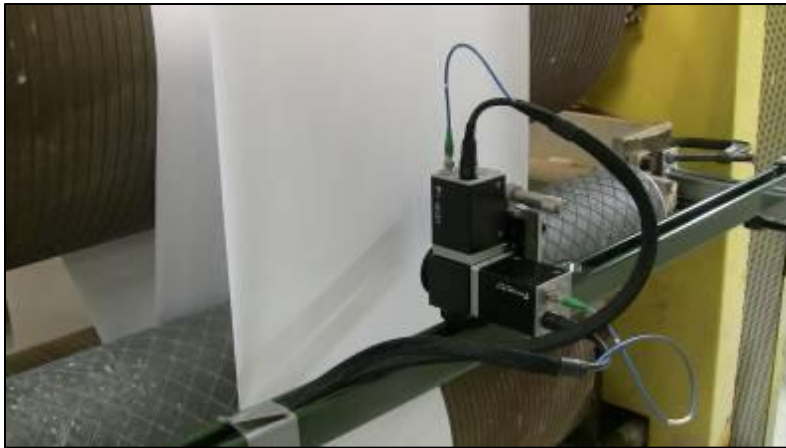
T-Gauge™
↓ - individual layers



Paper coating pilot line

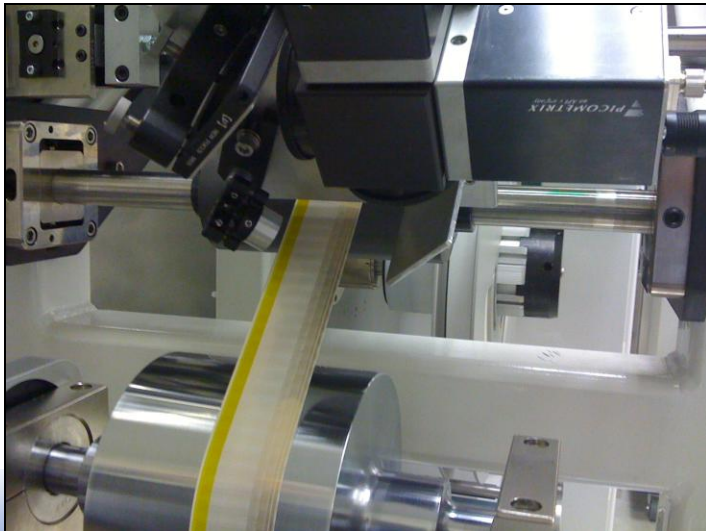
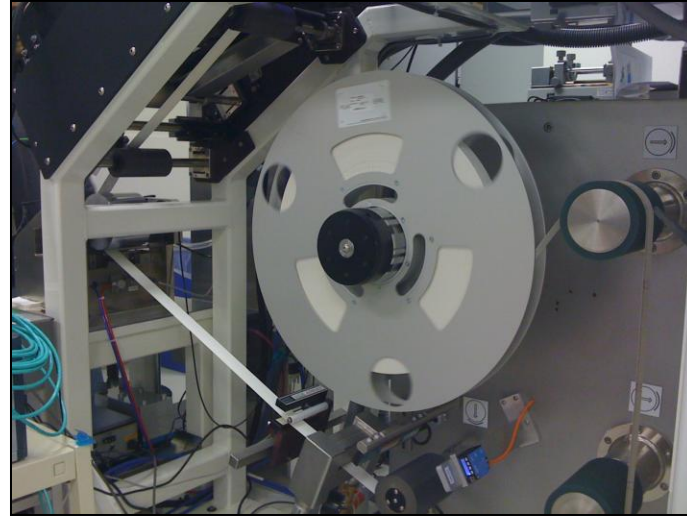


Two channel
coat weight
measurement



- Coat weight down to 1.5 lbs/ream measured
- Caliper thickness to .25 micron

Organic coating on plastic



Coating thickness: 60 microns
Accuracy: better than 5%
Web speed up to 1 m/sec

On a moving web

Thank you

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